MIT
Technology
Review

INDIA'S
ENERGY
CRISIS

P. 26

0 74470 01308 2

**When will
our devices think
for themselves?**

When we connected the phone
to the Internet, the phone
became smart. When our next
inventions connect billions more
things, life will be even smarter.

———————————

#WhyWait to join the discussion
Qualcomm.com/WhyWait

It's just human nature.

To be impatient. To want what's around
the corner to be in front of us today.

It's just human nature.

To be restless. Searching. Seeking.
Pushing to pull the future forward faster.

It's just human nature.

To create. To design. To invent. To build.

It's just human nature to ask:

Why not? And when?

To which we say,

Why Wait™

QUALCOMM®

From the Editor

Here are some English-language tweets from jihadis fighting for the Islamic State of Iraq and Syria, also known as ISIS: "I just noticed our martyred brother r.a. had a tumblr (I know, how could I have missed it). Make sure to check it out." And: "This Syrian guy next 2 me (AbuUbayadah) is so stoked for our op he almost shot his foot off. Come on bro—safety 1st. :p" And: "Put the chicken wings down n come to jihad bro."

In "Fighting ISIS Online" (page 72), *MIT Technology Review*'s senior writer, David Talbot, describes what a Google policy director has called the "viral moment on social media" that ISIS is enjoying. Talbot reviews the early and small-scale counter-efforts designed to "make one-on-one contact online with the people absorbing content from ISIS and other extremist groups and becoming radicalized."

He writes of a "decentralized" social-media campaign by ISIS, supported by sympathizers in the Middle East, North Africa, and elsewhere, who repost ISIS's gruesome videos or produce videos in their own languages that inflame local tribal and national grievances in an effort to join their regions to the self-declared caliphate.

The reason we care about ISIS's social-media campaign is that it has been an animating force in recruiting about 25,000 people to fight in Syria and Iraq, at least 4,500 of them from Europe and North America. Social media helped create an army that established a new state.

ISIS's viral moment recalls another recent historical moment in the Middle East when a movement was called into being by social media. In 2011, *MIT Technology Review* sent John Pollock to Egypt and Tunisia to report on the Arab Spring. At the time, journalists, new-media critics, and academics were engaged in an acrimonious debate about whether social media had been instrumental in the successful uprising against the dictatorships of North Africa. Pollock's reporting in "Streetbook" (September/October 2011) showed that there would have been no Arab Spring without Facebook, because social media "connected people to each other and to the world" and those connections allowed people to organize and protest on the street, "where history happens."

But Pollock's main insight was that we shouldn't be too surprised that a youth revolt used the preferred tools of the young: "The young make up the bulk of these movements, and inevitably they bring youth's character to their fight for change … Organizing or attending protests gets fitted between flirting, studying, and holding down a job. Action for this generation is as likely to be mediated through screens … as face to face."

So too, if less attractively, with ISIS. "In trying to understand why ISIS is so adept at [using social media to radicalize young Muslims], one comes back to a simple explanation," writes Talbot. "The people doing it grew up using the tools." Talbot quotes Humera Khan, executive director of Muflehun, a think tank that opposes extremism among Muslims: "When you say 'terrorist use of social media,' it sounds ominous, but when you look at it as 'youth use of social media,' it becomes easier to understand … Of course they are using social media! They are doing the same thing youth are doing everywhere."

The inescapable conclusion is that only widespread rejection of ISIS on social media by other young Muslims is likely to effectively counter ISIS's own social-media campaign.

But write to me at jason.pontin@ technologyreview.com and tell me what you think.

Contents

The Islamic State's mastery of social media, p. 72

November/December 2015

Back

ON THE COVER:

Illustration by Tomer Hanuka

JAVIER JAÉN

Smarter Embedded Designs,
Faster Deployment

The combination of NI LabVIEW system design software and reconfigurable I/O (RIO) hardware helps small design teams with varied expertise develop demanding embedded applications in less time. Using this graphical system design approach, you can take advantage of the same integrated platform to program embedded processors and FPGAs for faster application development in industries ranging from energy to transportation, manufacturing, and life sciences.

LabVIEW system design software offers ultimate flexibility through FPGA programming, simplifies code reuse, and helps you program the way you think—graphically.

>> Accelerate your productivity at ni.com/**embedded-platform**

800 453-6202

NATIONAL INSTRUMENTS

Feedback

Five Most Popular Stories

MIT Technology Review
Volume 118, Number 5

1

Tech's Enduring Great-Man Myth

Elon Musk (born in South Africa) isn't responsible for the Superman culture in the U.S. He's just satisfying the local market demand for supermen.
—**Miroslav Pivoda**

The article paints in black and white. Because the government sponsored a lot of fundamental research, it deserves credit. But it takes a man of grand vision and conviction to put together all the elements required. Imagine the first iPhone sold by anyone other than Steve Jobs. —**pallavsingh**

2

The Next Great GMO Debate

There are potentially unlimited different kinds of RNA, and the nucleotides in a strand of RNA are the major determinant of what effect the RNA will have on an organism. So yes, as the article states, we've been eating RNA as long as we've been eating, but that's like saying we've been eating food as long as we've been eating.
—**fanofhawking**

The 1 percent of insects that survive will be a different strain, and if the survivors are altered by RNA treatment, there is no way to predict what this shift in the insects' genome will cause. —**bubbabooboo**

3

Paying for Solar Power

The economics of solar without subsidies is stronger in areas without access to cheap natural gas or without strong power grids. This includes Spain, Japan and other island nations, India, China, and Africa. These markets will open up earlier for the solar cells from Buffalo than the U.S. market will.
— **gametheoryman**

When exactly are we going to end the billions in subsidies the fossil-fuel industry receives? This practice is so entrenched now that we don't even talk about ending a ridiculous long-standing largesse.
—**jcoleman**

4

Teaching Machines to Understand Us

I get nervous when I read statements like "LeCun says systems that grasp ordinary language could get to know us well enough to understand what's good for us." Once it can distinguish between "good" and "bad," who will control the decision-making process?
—**Rudolf01**

Given time, software will mimic that curious five-year-old, where every sentence is interrupted by a question. All the annoying but necessary details we adult humans need but rarely ask for.
—**websco137**

5

Inside Amazon

What a fascinating photo essay. Note the paucity of human beings in all these pictures of Amazon's massive warehouse operation. It seems as though robotization inevitably equals a reduction in rank-and-file workers with an increase in production efficiency. That's not necessarily a bad thing, but it's certainly something to ponder.
—**UConnRon**

Disgustingly beautiful.
—**Medhi B.**

Our RNA Delusions

Many of the biologists interviewed by Antonio Regalado in "The Next Great GMO Debate" (September/October 2015) believe we know enough about RNA biology to design novel RNA molecules that could manipulate the behavior of crops or their pests. All, presumably, without attracting the stigma of genetic-modification technologies.

So is using RNA in this way as safe as companies like Monsanto make it seem?

If you know where to look, there are plenty of scientific publications noting highly surprising results following interventions using RNA molecules. So far these findings have been largely ignored, perhaps because many biologists are unfamiliar with the chemistry of RNA.

The chemistry of DNA is familiar from high school textbooks. The hereditary material that cells must preserve at all costs, DNA is chemically unreactive, structurally inflexible, and almost immobile.

RNA molecules, however, are radically different. Best known as the intermediaries by which DNA codes for proteins, RNAs are chemically reactive. They are highly mobile within, and sometimes even between, organisms. RNAs are also flexible in their structures and chemically diverse (most people don't know that the familiar mRNA of high school texts comprises less than 1 percent of all cellular RNA). These characteristics give RNA a radically different risk profile from DNA's.

We don't yet know what caused the published surprises with RNA interventions, but one thing seems clear. RNA was probably the original molecule of life. To play with RNA is to reach deeper into the

> **If you look at the history of risk assessment, what we don't know tends to come back to haunt us.**

engine room of biology than ever before. And that's a problem. If you look at the history of risk assessment, what we don't know or fully understand tends to come back to haunt us.

Jonathan Latham, PhD, is the executive director of the Bioscience Resource Project.

HOW CAN WE MAKE SENSE OF VAST AMOUNTS OF COMPLEX AIRLINE DATA WITH A MYRIAD OF VARIABLES, CRUNCHING 6 HOURS OF INTENSE CALCULATIONS INTO 1 MINUTE, SO THAT HIGHLY VALUED CUSTOMERS LIKE STEVE MURRAY OF BROOKLYN DON'T SPEND HOURS WAITING AT THE AIRPORT FOR A DELAYED FLIGHT THAT WILL EVENTUALLY BE CANCELED, WHEN HE COULD HAVE STAYED HOME CELEBRATING HIS DAUGHTER'S SEVENTH BIRTHDAY?
IT'S SIMPLE.
THE ANSWER IS SAP HANA.

SAP HANA GIVES YOU THE AGILITY TO HANDLE ANY SITUATION.
For more, go to **sap.com/answers**

NOW WHAT'S YOUR QUESTION?

SAP

Run Simple

Views
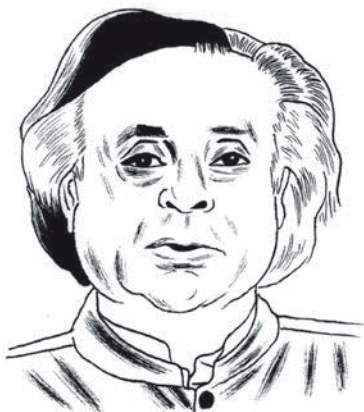
Jairam Ramesh

Margaret A. Boden

Thomas Insel

The Coal Conundrum

No matter what, India's use of coal will skyrocket in the next two decades.

India accounts for about 6 percent of global greenhouse-gas emissions. It's not in the same league as China, the United States, or the European Union, but that could change over the next two decades (see "India's Energy Crisis," page 26).

India has the world's third-largest reserves of coal. Coal now accounts for between three-fifths and two-thirds of the country's electricity supply, and even with the most aggressive plans to develop nuclear, hydroelectric, and renewable power, coal will still account for around half the electricity supply by 2030.

Nuclear accounts for only around 3.5 percent of India's supply. Raising this to even 5 percent over the next two decades would require heroic efforts. Hydroelectric power contributes around 17 percent of the power now, and although this could increase to around 25 percent by 2030, even hydro has social and environmental challenges. Renewables make up about 6 percent of the electricity supply, and current plans are to at least triple that in a decade and a half.

But even if India meets these bold targets, coal will still play the dominant role. With 50 million homes not yet electrified and with per capita electricity consumption at about one-third of Chinese and one-13th of American levels, India needs a huge expansion in generating capacity—another 15 to 20 gigawatts a year for the next two decades at least. Demographics can't be overlooked: India will add 400 million people over the next 30 years to its current population of 1.24 billion.

This is India's cruel coal conundrum. The country desperately needs to escape its dependence on coal, but it can't do so for at least two decades. The best it can really do is minimize the environmental costs of mining, transportation, and combustion. How? Carbon capture and sequestration is one option, but the most realistic method may well be a technology called integrated gasification combined cycle, which turns coal into gas. Still, "clean coal" is really a contradiction in terms.

India could learn a lot from the German *Energiewende,* which made a country with no real advantage in solar energy a world leader in that area. It's astonishing that Germany has 12 times the solar capacity of India. India's 500-megawatt fast breeder nuclear reactor is likely to be commissioned in 2016, paving the way for the use of thorium (a quarter of the world's thorium resources are in India). But India still can't wish away coal.

What India really needs is new research and technology development. And that won't happen without greater investment.

Jairam Ramesh is a former Indian minister of power and environment and the author of Green Signals: Ecology, Growth, and Democracy in India.

Artificial Creativity

Why computers aren't close to being ready to supplant human artists.

Artificial intelligence has an Achilles' heel. It can't decide what's relevant.

It just so happens that this is a crucial skill where creativity is concerned. Take computer-generated art. Such work has been well received in many prominent settings over the past few years—Ernest Edmonds's wonderfully colored interactive pieces (shown alongside Mark Rothko's canvases) in the 2007 "ColorField Remix" exhibition in Wash-

ington D.C., for example, and Richard Brown's *Mimetic Starfish*, commissioned for the opening of London's Millennium Dome, which the *Times* of London described as "the best thing in the Dome."

But those artworks didn't depend on a subtle appreciation of relevance. The Edmonds work is abstract: vertical stripes of ever-changing colors, with no representational content whatsoever. The *Starfish*, which brings to mind real-life animals and movements, and even natural reactions such as curiosity and alarm, has no specific cultural associations.

Or in the realm of music, consider the creativity of a DJ (see "The Hit Charade," page 78). What a DJ does is purely "combinational" creativity, or putting familiar ideas together in unfamiliar ways. DJs make no new music. Rather, they combine and order familiar pieces in unfamiliar ways. The value depends not only on the novelty of the DJ's choices but on their aptness: their capacity to remind us of musical or cultural associations that wouldn't have occurred to us otherwise.

The wider cultural associations are especially relevant when the music has lyrics. Think of "Eleanor Rigby" by the Beatles. However haunting the music, it would be less valued, and less memorable, without the words. The harsh discordance of the music and the near-savage sounds of the cellos reinforce the bitter sadness of the lyrics. They conjure up the loneliness and despair of Father McKenzie, as well as Eleanor Rigby herself, with extraordinary depth and richness.

A good DJ can take such things into account. For instance, a bitter song such as that one could segue into a sickly-sweet one, with the human audience enjoying the irony.

Pandora can't do that. AI's natural language processing is hugely limited by relevance blindness, the result of a computer that lacks semantic understanding or literary knowledge. Computers have written "novels," but the prose is horrifically bland. And computer-generated soap opera plots (which can ignore verbal and grammatical elegance) will win no Tonys.

We still need people for that.

Margaret A. Boden, a research professor of cognitive science at the University of Sussex, is the author of Creativity and Art: Three Roads to Surprise.

BIOMEDICINE

The Treatment Gap

We're still not taking mental disorders as seriously as we should.

There are several truths about mental disorders. The first is that they are associated with higher levels of disability than nearly all other medical disorders. Unlike most forms of heart disease and cancer, mental disorders often begin before age 30 and interrupt early careers. They are *the* chronic, disabling disorders of young people, and they're too often fatal. Suicide, nearly always associated with a mental disorder, kills more people than breast cancer or AIDS. There are more than 40,000 suicides a year in this country—more than twice the number of homicides.

Another truth is that disorders like depression, anorexia nervosa, and schizophrenia have mystified clinicians for centuries and remain no less mysterious today. Even our current tools for monitoring or manipulating the human brain are simply not up to the task of reading the language of the brain at the speed of thought. (However, we are getting better tools at an astonishing rate, thanks to the combined efforts of neuroscientists, engineers, computer scientists, and materials scientists in projects like the BRAIN Initiative—an effort to greatly improve our understanding of the brain.)

Our approach to treating mental disorders has changed radically over the decades. Once seen as psychic conflicts requiring psychoanalysis, they were later seen as chemical imbalances requiring medication. More recently, we've seen them as the result of abnormal electrical activity in specific circuits of the brain, analogous to an arrhythmia in the heart. Devices that deliver deep brain stimulation or transcranial magnetic stimulation are used to modulate this arrhythmia (see "A Shocking Way to Fix the Brain," page 54).

Another truth: psychotherapy, meds, and devices *all* work to one degree or another, but not everyone responds to all of these approaches, and some respond to none. We still don't know how to identify the best treatment for any individual. Some people with depression respond to cognitive behavior therapy, some to antidepressant medication, and some to deep brain stimulation. Some respond best to a combination of the three.

The inconvenient question might be, why are so few people in treatment? Fewer than half the people with a serious mental disorder like depression get treated. About half of those who receive treatment will get adequate or evidence-based care. And with our current options, only about half of those who get such care will recover completely. This means that only about 12.5 percent of people with a serious disorder are recovering.

Yes, we need better treatments based on modern science. But if we could improve access to today's treatments and deliver high-quality care, that would go a long way toward reducing the disabling effects of these disorders.

Thomas Insel, head of the National Institute of Mental Health since 2002, announced recently that he's leaving NIMH to join Google Life Sciences, part of the new conglomerate Alphabet.

Upfront

MATT PANUSKA

Farmers Plant Generic GMOs

Now that the patent on its genetically modified soybean has expired, Monsanto no longer controls one of the biggest innovations in the history of agriculture.

Billy Maddox planted 100 acres of Roundup-resistant soybeans this year. The big news is he didn't pay Monsanto a dime.

It's been 20 years since Monsanto developed its first genetically modified crops. Now some of its early patents are starting to expire, leading to the first "generic GMOs"—off-patent seeds that

Upfront

cost half as much and that farmers are free to save and replant.

Maddox, who spoke to me while driving down a road somewhere near Jonesboro, Arkansas, is a seed dealer who works with conventional varieties. This year was the first time he ever sold any GMOs. From the acres he planted, he was able to collect thousands of bags of seeds genetically engineered to resist glyphosate, the weed killer Monsanto markets as Roundup.

When the patent on a blockbuster drug ends, cut-rate competitors jump in and suck up market share. It's too soon to say if something exactly like that will happen with GMOs. "We've gotten calls from all over the country, but how big a deal it's going to be we still don't know," says Donald Dombek, director of the University of Arkansas Crop Variety Improvement Program, which developed the seeds Maddox has been selling.

The GMO market is big enough for competition, and it might need some: more than 90 percent of soybeans grown in the United States are genetically engineered with Monsanto's Roundup resistance genes. By the bushel, it's easily the most important biotech product ever.

Monsanto says it's not worried about the patent expiration. It developed a new version, Roundup Ready 2, several years ago that it says works better, and those

GMOs' Rise to Dominance
Portion of U.S. acreage planted with herbicide-resistant GM crops.
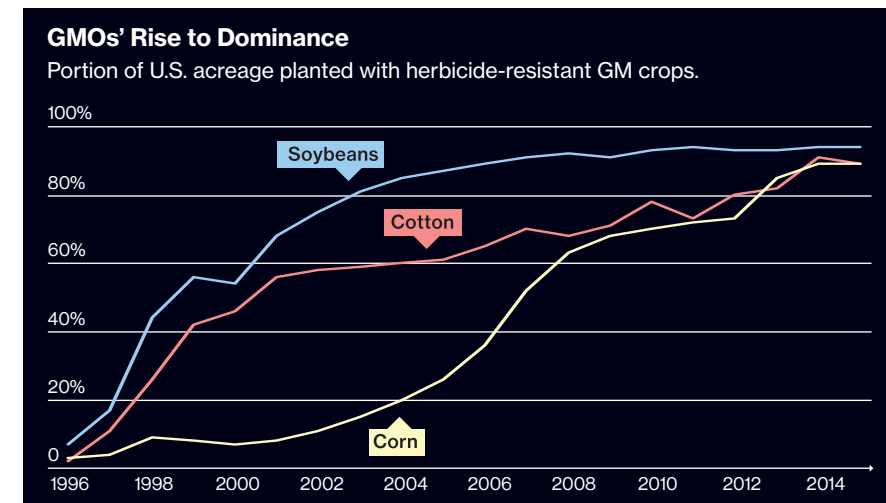
patents are still in force. A third generation is pending approval.

The generic GMOs Maddox planted were developed at the University of Arkansas by plant breeder Pengyin Chen, who spent several years mating plants in order to move the Roundup resistance gene, which originated in a bacterium, from Monsanto's seeds into a different type of soybean in development.

The resulting variety is called UA5414RR, and so far the university has sold 2,400 bags—mostly to seed dealers, who are growing more of it. Each bag weighs 50 pounds, holds about 140,000 seeds, and is enough to plant one acre.

Because there are 84 million acres planted with soybeans in the U.S., the market share claimed by Arkansas's seed is tiny. But agricultural universities in Kansas, Georgia, and elsewhere are launching their own generics. The University of Missouri, in Monsanto's backyard, is preparing four knockoffs to sell this year.

Farmers who want to plant off-patent GMO seeds will still need to check that they aren't encumbered by other restrictions. Apart from genetic engineering, any new plant variety can also be patented. Arkansas plans to file such a patent on its new soybean but says it won't stop farmers from saving seeds.

TO MARKET

Morph

Sensitive Touch Pad

COMPANY:
Sensel

PRICE:
$249

AVAILABILITY:
Mid-2016
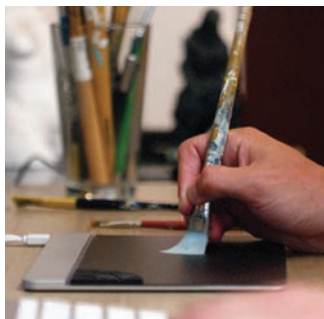
A startup is building a force- and touch-sensitive pad the size of a small tablet computer to be used as an alternative to a keyboard, mouse, or typical touch screen for all kinds of interactions with computers or tablets. Sensel's Morph relies on a grid of 20,000 tiny force sensors that can also figure out how hard all kinds of objects—fingers, brushes, pens—are pressing on it. Flexible overlays with embedded magnets can snap on top of the Morph, giving it the look of, say, a piano or drum pad, and software running on the device can interpret the touches (up to 16 at once) and map them to the different interfaces, the company says. —*Rachel Metz*

Chen says he created the new variety to give farmers a choice. They need to save money because prices paid for soybeans are at a four-year low. The Arkansas seeds cost $25 a bag, half the price of Monsanto's newer ones. But big seed companies are switching to Roundup Ready 2. They say the older trait had problems that led to lower yields, and they caution that university varieties aren't competitive. Even if the off-patent seeds were free, says Harry Stine, head of Iowa's Stine Seeds, farmers would still lose money by growing fewer beans. "There isn't anyone who can add and subtract who'd buy the cheaper, lower-yielding materials," he says. "But there are people who can't add and subtract, and so they will sell some."

According to Matthew O'Mara, an official with the Biotechnology Industry Organization, in Washington, D.C., a wave of important plant genetic modifications will lose patent protection starting in the next decade. That's been a looming concern for companies, he says, because of how biotech crops are regulated.

Monsanto says Roundup Ready 2 works better than its first, now off-patent seed.

China, which buys a quarter of the soybeans grown in the U.S., asks that genetically modified traits be reregistered every three years, he says. In Europe, it's every 10 years. Because of the way soybeans get mixed up in grain elevators and crushers, all exports could be compromised if approvals for older products lapse.

Although it doesn't sell the older Roundup beans anymore, Monsanto has said it will keep the regulatory files up to date through 2021. After that, keeping things on track may fall to an industry group set up to track expiring patents.
—*Antonio Regalado*

Construction Drones

Drones are being used to capture video footage that shows construction progress at the Sacramento Kings' new stadium in California.

For some construction workers, slacking off will soon be harder to hide. The drones will almost certainly notice.

Once per week, several drones circle the work site of a lavish new downtown stadium for the Sacramento Kings in California, collecting video footage. That footage is then converted into a 3-D picture of the site, which is fed into software that compares it with computerized architectural plans as well as a construction work plan showing when each element should be finished. The software can show managers how the project is progressing and automatically highlight parts that may be falling behind schedule.

"We highlight at-risk locations on a site, where the probability of having an issue is really high," says Mani Golparvar-Fard, an assistant professor in the department of civil engineering at the University of Illinois, who developed the software with several colleagues. It can show, for example, that a particular structural element is behind schedule, perhaps because materials have not yet arrived. The software is also being used at a high-rise construction project in Arizona and by Taisei, a large construction company in Japan.

While the construction company in Sacramento says the goal is not to monitor worker productivity directly, this development highlights the way new technologies allow manual work to be monitored and scrutinized. And it comes as productivity in other areas of work, including in white-collar jobs, is being tracked more closely.

Such scrutiny is sometimes controversial. It raises worries over privacy, for instance, and fears that people may be pushed to work excessive hours. Golparvar-Fard concedes that this could be a concern, but he defends the idea: "It's not really questioning the efficiency of the workers; it's questioning what resources they need to be more efficient."

Monitoring activity across a large, complex construction site is particularly difficult because there are so many moving parts, and because the jobs being performed change frequently. Lincoln Wood, regional manager for virtual design and construction at Turner Construction, which is running the Sacramento project, says that while it is common to monitor progress closely, the near-real-time aerial images and software analysis being used there provide a more comprehensive picture of what's going on, highlighting how a slowdown in one area may affect the entire project.

The University of Illinois team is currently testing a system that will allow drones to move cameras around a building site so that activity can be monitored continually. They are also using a crowdsourcing platform to categorize workers' activities in video footage. A manager can then see how certain tasks are being performed, and how much time each worker is spending on a job. —*Will Knight*
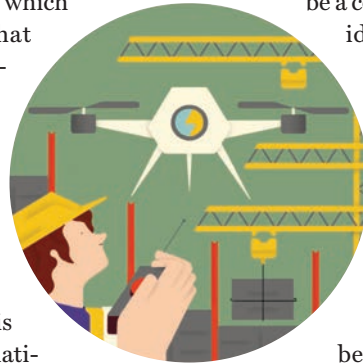
Upfront

Bionic Hearing Gadgets

Startups like Doppler Labs are building earbuds that will let you turn down the volume on crying babies and pump up the bass on live music.

In a windowless office on a tiny side street in San Francisco, Noah Kraft is making me hear things in a way I've never heard them before. I'm wearing a wireless earbud in each ear. The devices, which are white and look kind of like big Altoids mints, are the latest prototype built by Doppler Labs, a wearable-technology startup of which Kraft is cofounder and CEO. Kraft is sitting diagonally across from me, chatting, and using an iPhone app to manipulate the sound of his voice and the relatively quiet background noise of the office in ways that only I can hear.

He adds an echo to his voice. He raises and lowers the bass, treble, and midrange. Then he stands up and walks several feet away, but he sounds as loud as if he were yapping right in my ear—until I take out the earbuds and confirm that he's actually speaking pretty quietly.

Doppler is one of a few companies working on wearable gadgets that aim to augment the average person's hearing: you'd be able to adjust the bass and treble at a concert with a few swipes on an accompanying smartphone app, or block out specific noises like a crying baby or the hum of an airplane engine.

Doppler's first product, a pair of $199 earbuds called Here, will be aimed at audiophiles, and sales will be limited when they start shipping out late this year. They work by using algorithms to cancel out sounds you don't want to hear as they enter your ear, while letting through the sounds you do want. It's all controlled with a smartphone app, and the company plans to include settings for situations like live music and travel. When I tried it, it did work, though I didn't get to test it out in a stressful situation like a plane trip with a crying baby.

Nuheara, meanwhile, is trying to do something similar to Doppler but also plans to let users of its forthcoming wireless earbuds connect with digital audio—music, phone calls, and, on the iPhone,

With a few swipes, block the sound of a crying baby or the hum of an airplane.

Siri. David Cannington, a cofounder of Nuheara and its head of sales and marketing, says an iPhone app will let users do things like adjust background noise to enhance music they're listening to or boost their hearing in a noisy restaurant. Cannington says the company hopes to have a working prototype by the end of the year and to start selling the earbuds in late 2016 for "less than $300."

Like all kinds of wearables hitting the market, though, Doppler's and Nuheara's earbuds face formidable challenges with technology and comfort. Since they tend to use Bluetooth for communication between the in-ear device and a smartphone app, they depend on it to work well—and as anyone who's used a Bluetooth headset knows, the sound quality can be choppy even over short distances.

I didn't encounter this when trying Doppler, but I did notice some fuzzy sounds when my hair brushed past the earpieces. And sometimes when Kraft spoke to me I got the sensation of being in an empty concert hall or train station. As he explained, Doppler is still tweaking sound quality to get things like echo cancellation just right. —*Rachel Metz*

NIV BAVARSKY

REPUBLIC OF TURKEY PRIME MINISTRY INVESTMENT SUPPORT AND PROMOTION AGENCY

Software Development: Focal Point for Tech Growth in Turkey

No question about it: The information and communication technologies (ICT) industry is an essential driver of the global economy, helping to transform businesses everywhere.

That's especially evident in Turkey, where a large domestic market is creating enormous potential in the ICT sector.

ICT spending in Turkey is projected to increase, on average, nearly 7.5 percent annually over the next two years —significantly more than the world average, which Gartner Inc. estimates at 2.5 percent. Much of that growth will be concentrated on software development. Economic officials project that, by the time of Turkey's centenary in 2023, at least 3,000 software-development companies will be doing business in the country, up from about 1,000 today.

Cisco, Google, IBM, Microsoft, and Oracle are among the many global players in the Turkish software-development market. For example, Microsoft has located a regional headquarters in Turkey's financial capital, Istanbul; employees based there oversee Microsoft's business in nearly 80 countries in the Middle East and Africa.

Investor interest in Turkey's ICT sector has increased recently as well. The year's most notable transaction to date: In May, Delivery Hero, a global online food-ordering service based in Germany, acquired Yemeksepeti, a popular 15-year-old Turkish food-delivery portal, for USD $589 million.

According to a recent survey, companies operating in Turkey's ICT sector and related industries account for 17 percent of the country's fastest-growing businesses. Software-development firms, the largest subset of that sector, can recruit the employees they need from more than 250,000 graduates of Turkish universities who enter the job market with engineering degrees every year.

In the most recent Deloitte Fast50 Technology Turkey CEO Survey, executives of Turkey's fastest-growing technology companies identified these trends as most likely to drive technology investments for the next three years: Digitization and mobility, improved data analytics, and real-time information visibility and access. The CEOs also ranked the technology, media, and telecommunications sector as offering the most potential for their businesses over the next five years, ahead of financial services and health care.

Turkey's technology parks provide the optimum research and development (R&D) environment that the country's ICT industry needs for innovation and growth. Turkish officials expect R&D spending to account for 3 percent of the nation's gross domestic product by 2023. Turkey strongly supports R&D and innovation-related investments through its comprehensive incentive programs.

Fast Facts: Turkey's Current Standing in the Global ICT Industry

- Turkey ranks 11th worldwide in Internet penetration, with more than 37.5 million Internet users in a total population of 77 million.

- Turkey's Internet users spend, on average, 4.9 hours online and 1.9 hours on mobile devices every day.

- Turkey ranks seventh worldwide in the number of Facebook users (32 million) and 11th worldwide for Twitter users (7 million).

- Turkey is home to more than 10 million online shoppers. Its annual e-commerce growth rate hit 17 percent in 2014, surpassing Europe's overall growth rate of 11.8 percent.

- Turkey's business-to-consumer (B2C) e-commerce volume reached USD $6 billion in 2014.

Top Trends Driving Technology Investments in Turkey 2015-2018

Trend	Percent
Digitization and mobility	67%
Better use of data through analytics	60%
Increased visibility and access to real-time information	50%
Growth of e-commerce, need for multi-channel integration	43%
Increased focus on customer and services	36%
Concerns about cybersecurity	21%
Increased need for productivity	17%

Source: Deloitte Fast50 Technology Turkey CEO Survey, 2014

For more information, visit: invest.gov.tr

Upfront

More Life, Less Death

The United Nations has raised its projection for the world's population in 2050 to nearly 10 billion (see "India's Energy Crisis," page 26). While women are having fewer children, death rates are also dropping because of better health care and medical technologies.

Upward Trajectory
The population's growth rate is slowing, but only slightly. The U.N. estimates that the world will have 11.2 billion people in 2100.

2015
7.3 Billion

2030
8.5 Billion
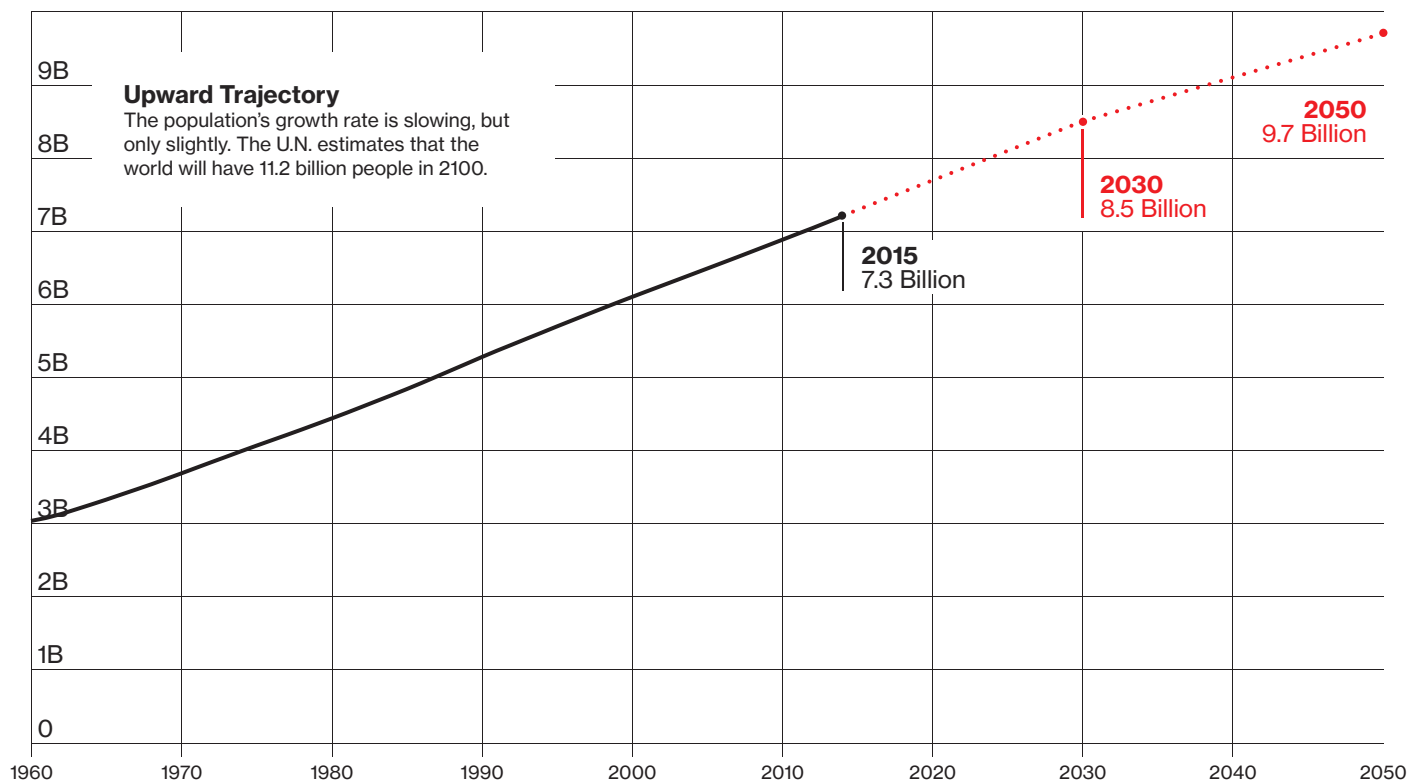
2050
9.7 Billion

Fewer Deaths

This reduction in the death rate will dramatically change global demographics. The UN expects that by 2050 people over 60 will constitute nearly 22 percent of the population, up from roughly 12 percent today.

Deaths per 1,000 people
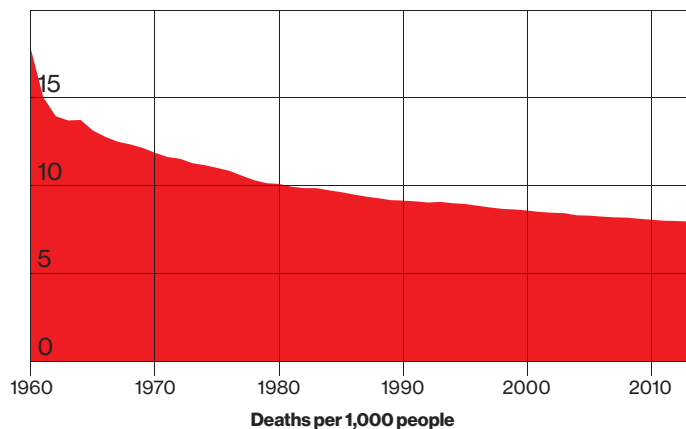
Better Outlook for Children

The falling death rate has been particularly striking for children, who are more likely to survive now because of better prevention and management of diseases like malaria, pneumonia, and AIDS. Many countries still have a long way to go, however.
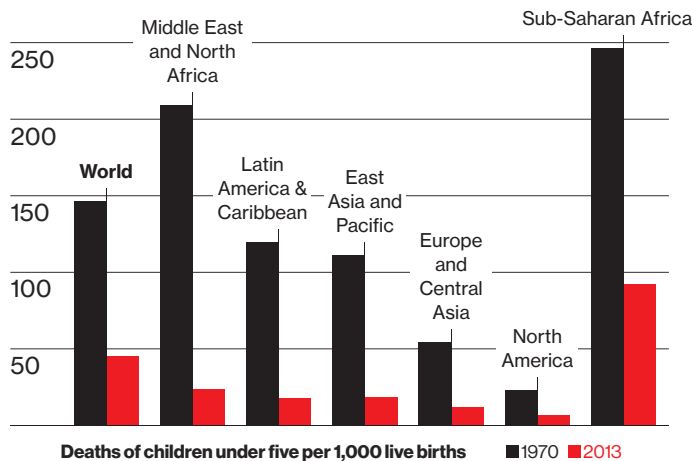
Sub-Saharan Africa

Middle East and North Africa

World

Latin America & Caribbean

East Asia and Pacific

Europe and Central Asia

North America

Deaths of children under five per 1,000 live births   ■1970 ■2013

Upfront

Gavin Andresen

Last year you stepped down after over three years as lead developer for the digital currency Bitcoin. Now you say it needs an urgent upgrade to handle more transactions. How serious is it?
Looking at the transaction volume on the Bitcoin network, we need to address it within the next four or five months. Networks close to capacity get congested and unreliable. If you want reliability, you'll have to start paying higher and higher fees on transactions. There will be a point where people stop using Bitcoin.

Some Bitcoin companies have endorsed your ideas, but others have attacked you and made counterproposals. What's happening?
It's somewhat chaotic. There's no well-defined process for coming to a decision about changes to Bitcoin, and there's no one correct answer for how to solve this problem. There's no single person making these decisions for Bitcoin; it takes consensus among the people running the software. It's a good thing that decisions like this are really hard to make happen.

Can you give us a sense of how widely established Bitcoin really is?
It's firmly established in a few niche areas and growing there. An early use case is people who pay international contractors in Bitcoin because it's easier than figuring out how to transfer dollars into local currency. The major barrier to it going mainstream anywhere is there has to be some way of getting Bitcoin as part of your normal activity. Until part of your paycheck is regularly paid in Bitcoin, I'm not sure how it would really go mainstream.
—*Tom Simonite*

Meltdown-Proof Reactors

Researchers say they could build a prototype of a molten-salt reactor—a safer, cleaner option for nuclear power—in 10 years.

For years nuclear scientists have talked about a revival of molten-salt reactors, which are powered by a liquid fuel rather than solid fuel rods, as a way to help spark the long-awaited "nuclear renaissance." Recent developments indicate that this alternative nuclear reactor design is finally making gradual progress toward commercialization.

A consortium of research institutes and universities working under the aegis of the European Commission recently embarked on a four-year research program designed to demonstrate the safety benefits of molten-salt reactors. Called "Safety Assessment of the Molten Salt Fast Reactor," or Samofar, the effort will lead to a prototype reactor by the early 2020s if all goes as planned.

First built and tested in the 1960s, molten-salt reactors would be the first genuinely new technology for nuclear power generation to reach the market in the last three decades. Producing zero carbon, they use a radioactive solution that blends nuclear fuel with a liquid salt. They can run on uranium but are ideally suited for thorium, an alternative nuclear fuel that is cleaner, safer, and more abundant than uranium.

Molten-salt reactors also offer inherent safety advantages: because the fuel is liquid, it expands when heated, thus slowing the rate of nuclear reactions and making the reactor self-governing. And they're built like bathtubs, with a drain in the bottom that's blocked by a "freeze plug." If anything goes wrong, the freeze plug melts and the reactor core drains into a shielded underground container. They can operate as producers of thermal power or as "burner" reactors that consume nuclear waste from conventional reactors.

While the advantages of molten-salt reactors have been understood for some time, they remain at the R&D stage because, in the post-Fukushima era of low-priced natural gas, it's hard to convince investors to fund any alternative nuclear technology. In the United States it can take a decade or more, and hundreds of millions of dollars, just to bring a new reactor design to the Nuclear Regulatory Commission for a license application.

Samofar is focused on fast reactors, which are more efficient than conventional light-water reactors and can breed fissile elements from nuclear waste. "Hopefully the results will also lead to much more commitment from the larger nuclear industry," says Jan-Leen Kloosterman, a professor of nuclear physics at the Technology University of Delft and the lead researcher on Samofar.

Getting that commitment remains an uphill struggle, but a report funded by the government of the United Kingdom and released recently by Energy Process Developments, a London-based research firm, reviews technologies from six potential developers of molten-salt reactors and finds encouraging signals for the next 10 years.

The most advanced program for liquid-fuel, thorium-based reactors is in China, where the Shanghai Institute of Applied Physics plans to build a prototype in the next few years. The Shanghai program is a collaboration with Oak Ridge National Laboratory, where molten-salt nuclear technology was born.
—*Richard Martin*
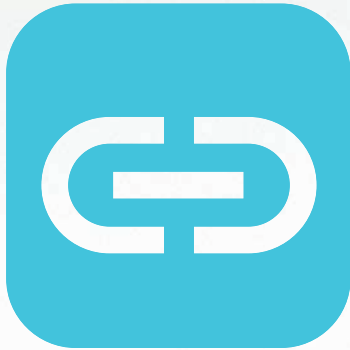
A new way to drive your apps.

Introducing SYNC® 3, with new hardware, new software and a new easy-to-use design.* Plus, SYNC AppLink™ lets you voice-control your favorite mobile apps.** And the responsive capacitive touch screen lets you swipe through them all. To learn more, visit ford.com/sync.

⊖ SYNC AppLink   Enhanced voice recognition   High-speed performance

🎤 Siri® seamless integration   📶 Automatic updates over Wi-Fi®†

INTRODUCING SYNC 3.
OUR NEXT GENERATION OF VOICE-ACTIVATED TECHNOLOGY.

Go Further

Upfront

"The whole company was designed to get the probability of success closer to one."

—Investor Peter Thiel on Stemcentrx, a biotech startup he's funding that's targeting stem cells to eradicate cancer.

"If a drone is bothering people, they're going to call the police, not the FAA."

—Aislan Foina, director of the Cal Unmanned Aviation Research Lab at the University of California, Berkeley, who is testing an LED-based license plate for drones.

"The population of car hackers is growing quickly."

—Joshua Corman, a security consultant for automakers, on the rise in car hardware hacks.

BY THE NUMBERS

1,000 °C
Temperature at which molten glass must remain in order to be used as "ink" for 3-D printing.

2
Number of Microsoft HoloLens headsets that ended up in the ocean after SpaceX's rocket blew up.

8
Number of successful heart transplants at Papworth Hospital in the U.K. after the organs were revived from dead patients.

72
Number of hours in advance an IBM computer system can predict how bad pollution will be in Beijing and other Chinese cities.

Pig Hearts for People

A biotech company is genetically engineering pigs so that their organs might work in humans.

With the financial aid of a biotechnology executive whose daughter may need a lung transplant, researchers have been shattering records in xenotransplantation, or between-species organ transplants.

The researchers say they kept a pig heart alive in a baboon for 945 days and also report the longest-ever kidney swap between the two species, lasting 136 days. The experiments used organs from pigs "humanized" with the addition of as many as five human genes, a strategy that is designed to stop a primate's body from rejecting the pig organs.

The GM pigs are being produced in Blacksburg, Virginia, by Revivicor, a division of the biotechnology company United Therapeutics. That company's founder and co-CEO, Martine Rothblatt, is a noted futurist, and one of her daughters has a usually fatal lung condition called pulmonary arterial hypertension. Rothblatt began spending millions to supply researchers with pig organs four years

ago and has quickly become the largest commercial backer of xenotransplantation research. She says her goal is to create "an unlimited supply of transplantable organs" and to carry out the first successful pig-to-human lung transplant within a few years. In addition to GM pigs, her company is researching tissue-engineered lungs and cryopreservation of organs. "We're turning xenotransplantation from what looked like a kind of Apollo-level problem into just an engineering task," she says.

Thousands of people die each year while waiting on transplant lists. Donated human organs are scarce, and because a heart or kidney lasts only a matter of hours packed in ice, many available organs can only reach the closest patients.

"We want to make organs come off the assembly line, a dozen per day," Rothblatt says. In 2011 her company paid about $8 million to take over Revivicor, and she has outlined plans for a facility able to breed 1,000 pigs a year, complete with a surgical theater and a helipad so organs can be whisked where they are needed.

The problem with xenotransplantation is that animal organs set off a ferocious immune response. Even powerful drugs to block the immune attack can't entirely stop it. In a famous 1984 case, a California newborn known as "Baby Fae" received a baboon heart. But it lasted only

three weeks before failing. The human body reacts even more strongly to pig tissue, since pigs are genetically more distant. All human tests of pig organs have ended quickly, and badly.

Researchers continue to work with pigs because they're in ready supply, and the organs of young pigs are about the right size. In order to beat the rejection problem, researchers began trying to genetically modify the animals. One major step came in 2003 when David

Revivicor plans to breed 1,000 pigs per year and send organs out by helicopter.

Ayares, a cofounder of Revivicor, created pigs whose organs lacked a sugar molecule that normally lines their blood vessels. That molecule was the major culprit behind what's called hyperacute rejection, which had almost instantaneously destroyed transplanted pig organs.

Removing the sugar molecule helped. But it wasn't enough. Tests in monkeys showed that other forms of organ rejection still damaged the pig tissue, albeit more slowly. To combat these effects, Ayares's team has made pigs with more and more human genes. "We are adding the human genes to the pig so you have the organ repressing the immune

response, rather than have to give a whopping dose of immune suppressants," says Ayares. By next year, some of the pigs will have as many as eight human genes. These genetic changes make their organs more compatible with a human body, but the animals still look and act like normal pigs.

Surgeons credit the genetically enhanced pigs with some recent successes. Muhammad Mohiuddin, a transplant surgeon and researcher at the National Heart, Lung, and Blood Institute, in Bethesda, Maryland, says a heart from one of Revivicor's pigs lasted two and a half years inside a baboon. The pig heart was attached to the baboon's circulatory system and was able to beat, but it didn't have to do the work of pumping blood, since the baboon's own heart remained in place. Mohiuddin says he'll soon begin trying to replace baboon hearts entirely. The organs he used before had three genetic alterations, but the next ones will have seven.

Transplant surgeons say one of the largest obstacles they face is the immense cost of carrying out xenotransplant experiments. A single transplant surgery costs $100,000. Then there's the cost of keeping the primates, the red tape of animal regulations, and limited government grants. That's where Rothblatt's personal interest and her fortune have made a difference, they say. —*Antonio Regalado*

India's

Can India modernize its manufacturing economy and supply electricity to its growing population without relying heavily on coal—and quite possibly destroying the global climate?

By Richard Martin

Photographs by Sami Siva

Energy

Crisis

An old man wakes on the floor of a hut in a village in southern India. He is wrapped in a thin cotton blanket. Beside him, music wails softly on a transistor radio. A small wood fire smolders on the floor, filling the space with a light haze; above it, the bamboo timbers of the hut's roof are charred to a glossy black.

The man's name is Mallaiah Tokala, and he is the headman of Appapur village, in the Amrabad Tiger Reserve in Telangana state. On his forehead he wears the *vibhuti*, the sacred daub of white ash. He is uncertain of his exact age, but he is well into his 10th decade. He has lived in this village his whole life, a period that encompasses the tumultuous 20th-century history of India: the rise of Gandhi, the Salt March, the end of the Raj and the coming of independence, Partition and the bloodshed that followed, the assassination of Rajiv Gandhi and the dawning of a new era of sectarian violence and terrorism. And now he has lived long enough to witness the coming of electricity to Appapur, in the form of solar-powered lights and TVs and radios.

On the wall of the hut a single LED lightbulb glows softly, connected through the roof to a black cable that stretches to a 100-watt solar panel on the roof of a concrete house nearby. It is a direct outcome of the policies of the central government, a thousand miles to the north in Delhi. Appapur is a "solar village," one of the showcases for the government's drive to bring solar power to small, unelectrified villages across India.

It's a huge task. At least 300 million of India's 1.25 billion people live without electricity, as the villagers of Appapur did until a year ago. Another quarter-billion or so get only spotty power from India's decrepit grid, finding it available for as little as three or four hours a day. The lack of power affects rural and urban areas alike, limiting efforts to advance both living standards and the country's manufacturing sector.

Since he took power in May 2014, Prime Minister Narendra Modi has made universal access to electricity a key part of his administration's ambitions. At the same time, he has pledged to help lead international efforts to limit climate change. Among other plans, he has promised to increase India's renewable-energy capacity to 175 gigawatts, including 100 gigawatts of solar, by 2022. (That's about the total power generation capacity of Germany.) And therein lies India's energy dilemma.

Already the world's third-largest emitter of carbon dioxide and other greenhouse gases, India is attempting to do something no nation has ever done: build a modern industrialized economy, and bring light and power to its entire population, without dramatically increasing carbon emissions. Simply to keep up with rising demand for electricity, it must add around 15 gigawatts each year over the next 30 years. The country gets most of its electricity from aging, dirty coal-fired plants.

(It has little domestic production of oil or natural gas.) And its energy infrastructure is in dismal shape. The obsolescence of its power grid was demonstrated by a massive 2012 outage that left more than 600 million people in the dark and drew attention to a utility sector in disarray, with an estimated $70 billion of accumulated debt.

If current trends continue and India follows the traditional path in which emissions increase as living standards rise, it will be disastrous not only for Indians but for the entire planet. By way of illustration, consider what's happened in China. From 1980 to 2010, while the country's per capita GDP grew by $193, to $4,514, its emissions per capita grew from 1.49 tons per year to more than six tons per year (these figures come from the World Bank and the CAIT Climate Data Explorer, maintained by the World Resources Institute). China is now the world's largest emitter of carbon. India's per capita emissions as of 2012, the last year for which figures are available, were 1.68 tons per year, and its 2014 GDP was $1,631 per person. Its population is expected to grow by another 400 million people over the next three decades, bringing it to 1.7 billion by 2050. If India follows a path similar to China's, that will add another eight billion tons of carbon to the atmosphere each year—more than total U.S. emissions in 2013.

Such growth would easily swamp efforts elsewhere in the world to curtail carbon emissions, dooming any chance to head off the dire effects of global climate change. (Overall, the world will need to reduce its current annual emissions of 40 billion tons by 40 to 70 percent between now and 2050.) By 2050, India will have roughly 20 percent of the world's population. If those people rely heavily on fossil fuels such as coal to expand the economy and raise their living standards to the level people in the rich world have enjoyed for the last 50 years, the result will be a climate catastrophe regardless of anything the United States or even China does to decrease its emissions. Reversing these trends will require radical transformations in two main areas: how India produces electricity, and how it distributes it.

Coal conundrum

The man charged with solving this puzzle is Piyush Goyal, the minister of power. (His full title is Minister of State with Independent Charge for Power, Coal and New & Renewable Energy.) With his political inheritance (his father, Ved Prakash Goyal, was a member of parliament and the minister of shipping under the government of Prime Minister Atal Bihari Vajpayee in the early 2000s), his suave manner, and his investment banking background, Goyal, 51, represents a new generation of Indian politicians from the Bharatiya Janata Party (BJP) who have come to power during the decline of the

Miners extract coal at one of the many mines in the Khasi Hills in Meghalaya.

once-dominant Congress Party. Despite the BJP's origins in the Hindu nationalist party that emerged in opposition to the more secular Congress Party, these younger politicians tend to be pragmatists, seeking to encourage economic growth through neoliberal policies such as deregulation and privatization of state industries. Since his appointment, Goyal has emerged as a champion of renewable energy, calling for investments of $100 billion in renewables and another $50 billion in upgrading the country's faltering grid. Almost every week he appears in the newspapers cutting the ribbon on a new solar power plant or wind farm or hydropower installation.

But he has also remained a staunch supporter of coal. He was exultant at the passage of a bill in March to guide expansion of the country's domestic coal-mining industry, saying it would boost the economy and create thousands of new jobs. While prices for electricity from renewable sources have fallen sharply in recent years, coal remains the cheapest source of power, and India's coal industry has embarked on a building boom, dou-

bling installed capacity since 2008. India consumes around 800 million tons of coal a year and could more than double that number by 2035, according to the World Energy Outlook from BP. To meet that demand, and to limit coal imports, Goyal plans to increase domestic coal production to 1.5 billion tons a year by 2020, from 2015 levels of 660 million tons. "Increasing domestic production of coal will be a big step towards long-term energy security of India," he said in a January tweet.

"India's conundrum is a coal conundrum," says Jairam Ramesh, a former minister of the environment. Ramesh, the chief negotiator for India at the international climate change talks in Cancún, Mexico, in 2010, is the author of *Green Signals: Ecology, Growth, and Democracy in India*. Last August, he welcomed me to the cramped, book-lined study in his home in Delhi and took me through the numbers on India's energy resources.

Almost 70 percent of India's electricity today comes from coal-fired plants. About 17 percent comes from hydropower,

29

Workers sort the coal according to quality at the fields in the Khasi Hills.

A worker prepares to crawl inside a mine in the Khasi Hills.

much of it from large dams in the northeast. Another 3.5 percent comes from nuclear. That leaves about 10 percent, depending on daily conditions, from renewables—mostly wind farms.

Over the next 25 years, "with the most aggressive assumptions in terms of renewables, we could go up to 18 or 20 percent from renewables," Ramesh told me. "Hydro takes longer—it involves displacement of people and submergence of land, but we could expect that 17 percent contribution to go up to 25 percent. Nuclear is at 3.5 percent right now and, under the most aggressive assumptions, could go up to 5 or 6 percent. So under the best scenario—the most aggressive programs for nuclear, hydro, solar, and wind—bloody coal will still be at 50 percent." In other words, while low- or zero-carbon sources would make up a greater portion of India's energy supply, overall carbon emissions would nearly double: from around 2.1 billion tons in 2014 to more than four billion tons by 2040, according to the International Energy Agency.

That's a discouraging conclusion. The response from Modi and Goyal has been to embark upon the world's most aggressive capacity-building program for low-carbon power generation. It was soon after taking office that Modi announced he would seek to add 100 gigawatts of solar power capacity by 2022. (India has about four gigawatts of solar capacity today.) Fifty-seven gigawatts of the planned new capacity is supposed to come in the form of utility-scale solar, including so-called "ultra mega" projects, ranging in size from 500 megawatts up to 10 gigawatts. "Ultra mega" hardly does justice to the scale of such gargantuan parks; the world's largest solar plant, the Desert Sunlight plant in California's Mojave Desert, is 550 megawatts. Twenty-five of these huge projects are due to come online by 2019, supported by 40.5 billion rupees ($649 million) in central-government funding—a paltry sum given that Desert Sunlight cost more than $1.5 billion to build. (In 2012, when Modi was chief minister of the state of Gujarat, he presided over the launch of the world's largest solar installation: a group

of plants totaling nearly one gigawatt combined.) Another 75 gigawatts of wind capacity is also planned.

Together, these additions would boost India's renewable capacity from around 10 percent of the total to as much as 32 percent. At the same time, the government plans a program of building nuclear plants that would roughly triple capacity by 2024 and supply one-quarter of the country's electricity needs by 2050. India also aims to further capitalize on its abundant potential for water power, particularly in the far northeastern states, where rivers tumble off the Himalayan plateau.

The fourth leg of India's low-carbon energy platform will be natural gas—if the country can find enough to import. India's domestic natural-gas reserves are small, and imports have been limited by the expense of shipping liquefied natural gas by tanker. But the conclusion of an international agreement to limit Iran's nuclear arms capacity, which would lift the international sanctions that have restricted Iranian energy exports, would give new momentum to the planned construction of an ultra-deepwater natural-gas pipeline across the Arabian Sea, from Iran to India's west coast.

Foreign companies are lining up to invest in India's renewable-energy sector (Softbank, of Japan, recently announced it will invest $20 billion in solar projects in India). But actually building all these new projects will be extremely expensive, requiring a level of fiscal discipline and political will that India's fractious, corrupt government has seldom achieved. Modi, who has surrounded himself with a group of capable, mostly well-respected technocrats like Goyal, has limited power to compel the states to implement and enforce clean-energy mandates, beyond the promise of central-government largesse. Rules requiring utilities to use a minimum amount of renewable power have mostly been ignored. Key pieces of legislation, including important amendments to the Electricity Act of 2003, are stalled in parliament because few of the country's politicians are willing to tackle the key issue: utilities are currently forced to sell electricity at below costs. Efforts to modernize the country's antiquated utilities—as must happen if there is to be any chance of implementing Modi's ambitious energy agenda—seem no closer to success than they did when he took office.

And then there is the question of how to pay for all the new renewable-energy installations. One hundred gigawatts of new solar capacity will cost in the trillions of rupees, requiring both higher electricity rates and massive funding from the central government. A 200-rupee tax on every ton of coal produced goes into a National Clean Energy Fund that now totals around $2.6 billion, but little of that has actually gone to developers and builders. At the same time, finance minister Arun Jaitley, at Modi's direction, is determined to reduce India's budget defi-

cit, currently around 4 percent of GDP. To overcome the likely shortfall, Modi and Goyal are, essentially, demanding that Western nations step in and finance renewable-energy programs in India and other developing countries. "The West will have to pay for the damage they have caused to the world and the planet," Goyal said in a climate-change address in London in May.

Another barrier to Modi's plans is that India imports nearly all its solar components. The "Make in India" campaign that he launched to encourage domestic manufacturing includes provisions to develop a solar manufacturing sector, but it will be tough to compete with low-priced imports from China in a country with a creaky industrial infrastructure, expensive capital, and little expertise in the technology.

In short, Modi is trying to create a world-class renewable-energy industry while reforming a corrupt and bankrupt utility sector, growing the country's manufacturing sector, keeping deficits low, and sustaining economic growth at around 8 percent a year. If all that happens—if the grandiose solar plants get built, and new dams arise in the north, and the nuclear plants get financed, and the deepwater pipeline gets laid—India could, perhaps, solve the conundrum of "bloody coal" and overhaul its power generation system. That, however, would still leave one large problem: transmitting and distributing all the electricity to consumers.

The last mile

Kishan Lal met an ignominious end. On the evening of June 24, the 40-year-old fruit and vegetable vendor went to relieve himself in a public toilet in Shakarpur, a district of east Delhi, and made the mistake of touching a metal rail inside the loo. He was electrocuted and died instantly. India's power grid is dangerous because it's haphazard and often improvised. Power theft, known as *katiyabaaz*, is rampant; even legal connections are often jury-rigged. Snarls of lines enveloping the tops of leaning electrical poles are a ubiquitous sight in every Indian city.

Power losses in transmission and distribution across India average around 25 percent, and in some areas they can reach 50 percent. That means that half of the electricity being generated either never reaches an end user or is used but never paid for. Power losses in the developed world seldom reach 10 percent. For a grid about to be tested by the addition of large amounts of power from intermittent renewable sources, that outdated infrastructure is a huge problem.

It's compounded by the fact that so many of India's citizens aren't on the grid at all (no count is precise, but the number is probably somewhere between 300 million and 400 million). Not only do power lines fail to reach many rural areas, but many of those living in city slums are also without utility services

(often they simply cannot afford the estimated $105 it takes to connect to the grid, even if such connections are available). The Power Grid Corporation of India operates more than 70,000 miles of transmission lines that stretch across most of the sub-continent. What had been five regional grids have been united into a single national system that reaches to within a few miles of most of the population, a process completed in 2013. The grid's transmission connections between regions remain inadequate, however—this was the primary cause of the 2012 black-out—and India's switching and control technology has been little upgraded in the last two decades.

What's more, the buildup of generation capacity in the last decade has not been matched by investments in power lines and substations. India's grid operator plans to spend one trillion rupees ($15 billion) over the next few years to add nine new high-capacity transmission corridors—a sizable fraction of the $50 billion that Goyal has said will go to modernize the grid over the next decade.

In theory, such funding should make work easier for people like Pawan Kumar Gupta, the general manager of the State Load Despatch Centre, the main grid operations center for the nation's capital. Outside the Despatch Centre, I saw the same tangled, sagging wires that lead to just about every building in Delhi; inside, the corridors were empty and dusty until we passed through a series of secure doors to reach the control room. There, a wall-size screen monitors the various feeders and substations for the five distribution utilities that serve the metropolis. On the board, green and yellow flashing numbers showed the amount of electricity flowing across the system. The function of the Despatch Centre is to match supply and load, or demand.

Demand goes up and down, but the supply is fixed. Nation-wide, the country runs an annual energy deficit of 5 percent; in other words, it produces only 95 percent of the power it needs. In many big cities the deficit creeps upward to 20 or 25 percent. When the power's not available, the Despatch Centre throttles down; the result is the daily rolling brownouts that plague Delhi, along with most other Indian cities. With grid power uncertain, major Indian companies such as IT giant Infosys have installed their own power plants: Infosys is planning a 50-megawatt solar park to serve its offices in Bangalore, Mysore, and Mangalore.

Under so-called renewable-purchase obligations, instituted under Modi's predecessor, distribution utilities, which deliver power to end users and are known in India as "discoms," are required to provide certain levels of electricity from renewable sources (7.3 percent of their total supply in 2014–2015; the level goes up each year). Their actual progress toward meeting

*Electric towers line the highway
in New Delhi.*

A residential colony endures a blackout in New Delhi.

those targets has been limited, though, and the penalties for not doing so are negligible.

If the utilities do manage to use more renewable energy, they will require major upgrades to the local distribution grids, to balance loads and ensure that the power supply is stable even when the sun's not shining and the wind's not blowing. Will the money come in time, if it comes at all? When I asked Gupta, he laughed out loud and threw up his hands. "It will be a very challenging job, no doubt," he said, smiling.

The practical job of dispensing power was made more difficult by the victory in February's municipal election of the Aam Aadmi Party, which ran on a platform of steep discounts for water and power. Promising free water and electricity, without specifying a way to pay for it, is an old tradition in Indian state and local election campaigns. Under the Aam Aadmi Party's platform, Delhi families will get 20,000 liters of free water a month, and those who use less than 400 kilowatt-

hours of electricity per month will get a 50 percent discount on their electric bills. Those subsidies will cost the government up to 16.7 billion rupees ($250 million) annually—and they will not help the discoms run profitable businesses.

The Delhi discoms, though, are models of financial stability compared with many of their counterparts across India, especially those that serve rural areas. Under the agricultural subsidies that have become the third rail of energy politics in India, farmers essentially get free power, which means the utilities that serve them lose money on every customer. Some of the loss is made up in handouts from the central government—but upgrading the grid will be of little use unless utilities can develop viable business models. The sector has been bailed out, to the tune of billions of rupees, twice in the last 13 years. The cumulative losses have increased so drastically that they could "pull down the whole growth agenda" of the Modi government, says Praveer Sinha, the CEO of Tata Power Delhi Distribution, one of the major Delhi discoms.

Children study by the light of an LED lamp powered by a microgrid in Biswan, Uttar Pradesh.

The landmark Electricity Act of 2003 instituted certain broad reforms, introduced elements of privatization, and created more consistent national rules governing the generation and transmission of power, but its provisions have been implemented spottily in some states and not at all in others. In May 2015, Goyal announced the National Smart Grid Mission, which will provide grants covering up to 30 percent for upgrades to regional and local grids. Two months later he unveiled a 20-year plan to upgrade the national transmission network, including an exemption from interstate transmission charges for power from renewable sources. Discoms in many states have announced rate hikes ranging from 5 percent to 45 percent.

Full reform, however, will require steps that remain politically off limits for now: complete privatization, less interference by state governments in utility operations, and, above all, an end to free electricity for farmers.

In the cities, meanwhile, discoms intent on modernizing—and getting customers to actually pay for their power rather than steal it—have been forced to broaden their scope. Tata Power Delhi, a subsidiary of the giant Tata conglomerate, has instituted a series of social programs, including free life insurance, medical care, and literacy and vocational classes, in order to try to persuade people to stop stealing power and pay for metered electricity.

At one literacy program funded by the company, in a slum in Pitam Pura, in northwest Delhi, a dozen or so women crowded into a small room in a concrete building on a Tuesday last summer. An ancient desktop computer occupied a small table in a corner. Outside, the usual nest of electrical wires led to a meter on the wall of the building. Kusum, who gave only her first name, said that she and her family started paying for electricity a year ago, along with most of her neighbors.

The earlier system of *katiyabaaz* "was just the common practice," she said through an interpreter. "We didn't think we were doing anything wrong—it was just the way of life."

Clothes dry on power lines in a slum area in New Delhi.

Evening at Khan Market, an upscale shopping area in New Delhi.

Her husband is a day laborer who works when he can find employment. The monthly family income of Kusum, her husband, their three sons, and one granddaughter, who all occupy a single room of about 150 square feet, is about 10,000 rupees ($150). Out of that, the family now pays around 510 rupees a month for electricity. That makes life more difficult. "But I don't live in fear of accidents anymore," she adds. "We feel more at peace, and safer, and we have more pride to know that we're not stealing."

Bringing new customers like Kusum onto the grid, legally, is a step toward rationalizing the utility business. But such stories are always dwarfed by India's vastness. Kusum's is a relatively small slum of perhaps 21,000 people. That's a tiny fraction of the population of India's second-largest city, and not every utility has the wherewithal to become a social-services agency in addition to providing electricity.

In any case, reducing power theft among the urban poor will solve only one of many problems for India's grid. In many places, villagers who can see the poles and power lines from their homes could wait decades for those lines to reach them. Expanding the grid to reach every home and business would require many trillions of rupees that the central and state governments simply don't have. For many, gaining access to electricity through solar microgrids and other local power sources that bypass the traditional utility model is a far more practical option.

"I don't agree to the one-size-fits-all mechanism," Goyal told the national *Business Standard* newspaper in June, adding that individual state-by-state plans for power-sector reform would be issued by mid-2016. The wider implication is that India's energy problems will require solutions tailored to the country's history, its technology and economy, and its place in the world.

The solar bubble
Although Appapur is located inside a tiger reserve, the real problems are leopards, snakes, and wild boars. Leopards take

A slum area where Tata Power supplies electricity.

10 to 15 domestic cows and goats a year, local people told me when I visited in late July. Boars destroy the small food gardens the villagers cultivate. Venomous snakes coil in the grass, a hazard for those walking in the dark. Solar lighting in the evening, made possible with 100-watt panels and lead-acid batteries, has reduced these problems but not eliminated them; the leopards sometimes hunt by day as well as night, and the boars are brazen at all times. A solar-powered electric fence would take care of the animal threats, people told me, but they realize that is years away at best.

The most dramatic changes the small solar systems have wrought in the community are in education and social life. Children have light to read and study at night. A few TVs provide a link to the outside world (there was no Internet service, and no computers, in Appapur when I visited). The outdoor lights, though there aren't many, bring people together to relax, socialize, and discuss the village's problems in ways that were impossible in smoky, cramped, kerosene-lit huts.

"We can communicate more with our neighbors," says T. Jaya Lakshmi, the granddaughter of village chief Mallaiah Tokala and the director of Appapur's one-room school. "We have more of a sense of community because we're not afraid to go out at night."

The most urgent need now is water. Before the solar panels were installed, a crew came and dug a well near the huge banyan tree that marks the center of the village. Later a couple of panels were hooked up to run the pump, but they proved insufficient. Officials promised to return with more panels. That was more than a year ago. Today people must still walk two kilometers to fetch water.

India has thousands of unelectrified villages where the people still live in darkness. Most will never be connected to the grid. Rooftop solar power—or, alternatively, microgrids powered by various combinations of small renewable installations and diesel generators—are the only way their inhabitants will ever get reliable electricity. A number of Indian and for-

*A family in Sureshpur village in
Biswan, Uttar Pradesh.*

A farmer returns home near the wind farms in Coimbatore, Tamil Nadu.

eign providers, including fast-growing companies like Visionary Lighting and Energy and Greenlight Planet, are spreading small home solar systems across South Asia, driven by government incentives, plummeting costs for the technology, and high demand.

But small-scale solar is a tough, low-margin business. The money, at least for now, is in large, government-supported solar parks. The rush to build solar projects in India has officially begun. This year analysts expect the country to add 2.5 gigawatts of solar capacity, more than double the total added in 2014. In phase one of the National Solar Mission, the government is soliciting bids to build 15 gigawatts of capacity across the country.

The results of the government's first solar auctions have been striking. In one, held in Madhya Pradesh, Canadian developer SkyPower won the bidding with an offer of 5.05 rupees (about 7 U.S. cents) per kilowatt-hour. That auction, offering the chance to build 300 megawatts of solar capacity, was

so oversold that it attracted bids totaling 2,200 megawatts, at rates well below the 7.04 rupees per kilowatt-hour that the Central Electricity Regulatory Commission has determined is the threshold of viability for solar photovoltaic projects.

In other words, solar builders in India are bidding unrealistically low prices for these projects, counting on the Indian government to make up the difference. Indeed, the government has initiated a "viability gap funding" scheme for public-private infrastructure projects, which will provide grants to solar developers "to support infrastructure projects that are economically justified but fall short of financial viability."

Whether or not that funding will be enough to make these projects viable or profitable over the long term, the solar balloon in India continues to rise. When I met SkyPower CEO Kerry Adler, he vehemently defended the Toronto-based company's India strategy and the prices at which it plans to build solar parks. "There are some suicidal bidders out there," Adler acknowledged, but "SkyPower has never secured a contract it

An engineer inspects solar panels on the rooftop of a warehouse in New Delhi.

has failed to build. We've never lost money on one of these projects, and we don't intend to start now."

Be that as it may, some of India's currently planned utility-scale solar projects will never get built, while others will get built and fail. And even the successful ones will not be sufficient to solve all of India's energy challenges. Jairam Ramesh, the former environment minister, suggests that the country needs to think differently about renewable energy sources and not expect them to primarily serve "this vertically integrated model of electricity generation, where the bigger the [project the] better." In some cases, smaller will be better.

Brick factories

That transformation is already happening. In southern Indian cities like Bangalore, many rooftops already have water tanks heated with solar energy, and the number of states that require rooftop solar on new construction is multiplying. Every town in India, even the dustiest roadside hamlet, has banners and billboards advertising small battery and inverter systems. A new energy ecosystem is arising in complex and not always predictable ways.

One day last summer, I visited a solar test site in a walled compound near the town of Challakere, in the dry scrubland a few hundred kilometers north of Bangalore. Run by the Bangalore-based Indian Institute of Science (known as IISc), it's a concentrated-solar-power test array. Rows of shallow parabolic troughs, made of specially coated aluminum, stretch the length of more than two and a half football fields. Sunlight reflected from the troughs is concentrated onto water pipes above. Started up this fall, the system heats water in the pipes to 200 °C; the hot water goes to a heat exchanger attached to a small turbine that produces 100 kilowatts of electricity.

Funded by the Karnataka state government and the Solar Energy Research Institute for India and the United States, this array will be used to test various reflective materials and heat-transfer fluids (including, for instance, molten salt in addition

to water). The objective, says IISc professor of materials engineering Praveen Ramamurthy, is to find the best combinations of components specific to conditions in India, a process that is badly needed for solar photovoltaic technology as well.

"Nobody is testing for the aging [of solar equipment] in India," says Ramamurthy. "We get solar panels, but they're certified for moderate climates in the U.S. and Europe, and we just adapt."

Among the hazards to solar arrays in India are high temperatures and humidity, which tend to rot the adhesives that hold together conventional solar panels. Dust and degradation are also major problems. Ramamurthy is developing polymer composites to seal in and protect the photovoltaic cells. Solar photovoltaics will be the main source of solar power generation in India, but concentrated solar power is also of keen interest, because it can be used in ways other than generating electricity. Across India, for example, are small, independent factories that produce bricks by baking them in wood-fired stoves. That causes deforestation and heavy emissions of carbon dioxide. Using concentrated solar to bake the bricks would be a huge boon to the environment.

Such tailored solutions may seem inadequate to the scale of the challenges. The combination of failing utilities, heavy reliance on coal, a faulty grid, and an energy sector crippled by government subsidies and interference seems to argue that India has no chance: no path to economic growth and energy abundance except one that's disastrous for the environment. But at ground level, the picture is more complicated and less bleak.

"The central government and outside investors are, naturally, focused on these big mega-projects, where they're getting ridiculous financing, but the real innovation is happening at the village level," says Anshu Bharadwaj, the executive director of the Center for Study of Science, Technology, and Policy, a Delhi think tank. "The most impactful way is to develop a large number of 100-kilowatt, half-a-megawatt projects that are distributed across the country, close to rural loads."

Ultimately, some combination of distributed solar power, local microgrids, and large renewable-power plants will be needed to address India's energy needs over the next 50 years. You can't extend the grid to every village and hut in India, but you also can't develop and operate a 21st-century manufacturing base using unpredictable distributed solar power. The key will be figuring out what works on a state-by-state, city-by-city, village-by-village level. That work is already being carried out in the state of Bihar, by a team of researchers connected to the Tata Center for Technology and Design at MIT. Bihar is typical of India's rural states: it has more than 100 million people, less than one-fifth of whom have access to reliable electricity.

The state discom is more or less bankrupt, subsidized electricity bills are artificially low, and electricity losses on the grid are close to 50 percent. The reach of the grid is random, says Ignacio Pérez-Arriaga, a visiting professor at MIT and head of the Reference Electrification Model, which is focused on planning electricity access for India and other developing countries.

"I visited a village today that doesn't have electricity," he told me in July, "and 100 meters away, the next village has good electricity. It's confusing. They may get it next month, next decade, or never."

Paradoxically, the sheer size of the task ahead—the fact that India is in the early stages of upgrading and modernizing its energy system—is in some ways an advantage. It happens to be embarking on its modernization phase at a time when prices for renewable-energy generation, and for the technology to make it work at the local level, are starting to rival prices for traditional fossil-fuel-generated power.

BMW, for example, said earlier this year that it will build a solar plant to meet 20 percent of the power demand at its factory near Chennai. Indian Railways, which operates the most extensive railroad system in the world and is the nation's largest employer, plans to build a gigawatt of solar capacity in the next five years. By avoiding the cost of providing universal, grid-based electricity, India can concentrate on what works best for specific locations and specific needs. Every microgrid and local solar system deployed reduces by a fraction the need to extend the grid; every new renewable-energy system installed by a business or factory reduces the pressure to build ultra-mega power plants.

Because it's industrializing now, India has the chance to remake itself using rapidly improving technologies. Today, it's requiring new buildings to be solar-equipped and deploying entrepreneurial distribution models that bypass the broken utilities. Tomorrow, it could be relying on concentrated solar for small factories, or small nuclear reactors, or some other generation and distribution model that has yet to emerge.

That sense of dynamic possibility and improvisation was evident everywhere I went in India, from Delhi's slums to the villages of Telangana. The Indian genius for adaptation and survival in chaotic and challenging circumstances provides hope that the country can solve the seemingly insurmountable challenge of expanding its economy in a clean and sustainable fashion. In many ways there is no choice. "India cannot afford to replicate the American or Chinese 'Grow now, pay later' model," says Jairam Ramesh. "We cannot afford to say, 'We're going to have 25 years of 8 percent GDP growth, then do a cleanup act later.'" ✠

Richard Martin is MIT Technology Review*'s energy editor.*

How Uber's archenemy plans to make the world a better place by building a kind of public transit system from private cars.

By Ryan Bradley

Illustrations by Golden Cosmos

Lyft's Search for a New Mode of Transport

We were all in the car with Alexandr, listening to techno, which was his choice. He was driving; it was his car. As we crawled east across Los Angeles, through Hollywood, the two strangers seated behind me argued about whether you could call yourself a photographer if you only posted your photos on Instagram. None of us had met until five minutes before, and after Alexandr dropped us in the different places we were going, we'd probably never see each other again.

Logan Green, CEO of Lyft, the company whose app brought us four strangers together, thinks encounters like this are the future of urban transport. They're going to make it greener and more efficient while saving Lyft from being crushed by its competitor Uber, which has more than eight times Lyft's $1 billion in funding and several times Lyft's roughly 100,000 active drivers.

Lyft and Uber use the geolocation functions of smartphones to link car owners willing to play cab driver with people willing to hop in a stranger's car. Millions of people do it every day, even though the services launched only a few years ago. By sidestepping taxi regulations, making payment automatic, and finding a way to precisely locate drivers and customers, Lyft and Uber were able to uncover an astonishing untapped demand for a better way to get around urban areas. When asked to explain the secret, Green takes a characteristically long pause and describes it as "optimizing around the two things that are most important to you: time and money."

This optimization has been most dramatic in San Francisco, where Green and I met, and where both Lyft and Uber are headquartered. Here many people routinely ignore cabs, buses, trains, and even car ownership and instead Uber or Lyft—both are now verbs—everywhere they go. Uber is trying to make all the world's cities, from Bangkok to Bogotá, like San Francisco: it already operates in 61 countries. Lyft only just made its first overseas venture, a partnership with a leading Chinese ride-hailing company, but Green's strategy is ambitious in another way. He's trying to reinvent the taxi-replacement model that has powered the swift rise of his company and its dominant competitor. According to Green, Lyft's future—and that of urban transport itself—involves many more rides like my techno-soundtracked trip across Hollywood. That journey was made using a carpooling service that the company calls Lyft Line. Green envisions drivers using it to pick up passengers along their own commutes, school runs, or trips to the store. "This idea that every car on the road can be a Lyft, that becoming a driver is as easy as requesting a Lyft—that's core to our mission," he says. If that mission succeeds, people might get to where they're going much more cheaply than they can with a regular Lyft ride, or even a car of their own, because every seat in every car might be filled. As a bonus, congestion and pollution would be slashed. He predicts that car ownership will plummet.

Regular Lyft rides can be two-thirds of a taxi fare or less, but a Lyft Line ride is even cheaper, and the company aims to shrink the price further. Green says this makes Lyft something new: a third category of transportation somewhere between public and private. That afternoon in Hollywood, sharing a stranger's car with other strangers because we all needed to get across town, it cost me $15.67 to make the 35-minute trip. I saved $1.63 by sharing with the Instagram argument guys, though I tipped Alexandr $1 of that because I'd put in the wrong destination, making him drive a minute or two out of the way. An online taxi fare estimator for Los Angeles says I would have paid more than $33 in a cab.

Lyft remains tiny compared with Uber. At a hearing in New York in June, the company revealed that it provided 7 percent of rides summoned over the Internet in that city, compared with Uber's 90 percent. Uber also has an equivalent to Lyft Line, called UberPool, although it doesn't yet offer an easy way for drivers to pick up passengers during a journey of their own. Green argues that Uber isn't friendly enough to its drivers to make sharing your car attractive to a broad audience. (A year of using Lyft in Los Angeles and San Francisco suggests to me that Lyft drivers, many of whom have driven for Uber, do feel more respected.) And there is evidence that Lyft's strategy is working. In San Francisco, the company's biggest market and one it says is already profitable, most Lyft rides are Lyft Lines. In San Antonio, where Uber, Lyft, and similar services were kicked out by city legislators, Lyft won its way back in this August and is, for now, sole operator after lobbying the mayor to embrace Green's vision for an efficient and democratic form of transport. Now Green must convince other officials, and millions more customers, that sharing rides with strangers in private cars is something everyone should do, any time.

Transit obsessive

Green, now 31, grew up in Los Angeles, the only child of a veterinarian mother and a physician father. His formative transit experience, like that of many L.A. children of the 1980s and '90s, was sitting in gridlocked traffic to and from school, three hours every weekday. By his teens, he ran a small tech tutoring and troubleshooting business for "old folks" (a.k.a. adults) and worked summers at a startup run by Nolan Bushnell, the man behind Atari and Chuck E. Cheese's. Green was on its engineering team. He administered a rewards program that connected arcade games in different locations and piped user data back to company headquarters. The work nurtured his natural urge to optimize, which gnawed at him as he sat in traffic. Most cars had only one person inside, despite the fact that many of those lone drivers were headed to pretty much the same place. "This has got to be the worst way of organizing people," he recalls thinking.

Green studied business economics at the University of California, Santa Barbara, but he effectively majored in transportation. To force himself to understand the alternatives to driving, he left his 1989 Volvo back in Culver City with his folks, putting himself at the mercy of the bus system. "Let me use it and let me get frustrated by how bad the service is," he resolved.

Santa Barbara is a preposterously beautiful and wealthy little city. It does not seem like a very good bus town, but it is, or was. I grew up there, and I rode the bus to junior high occasionally. Summers in college I took the bus downtown, to

"This has got to be the worst way of organizing people," he recalls thinking.

my job at the local alt weekly, where we spent a little time covering the improbable election of a UCSB senior to the city transportation board. That senior was Green, who by then had already spent years trying to improve how people got around. By sitting in on city planning meetings as a sophomore, he had learned about the then-new idea of car-sharing schemes, where people rent communal vehicles by the hour. Green launched one on the UCSB campus: six Priuses, used by a few thousand students and faculty members. He also came to chair the UCSB Parking Rate Payers Board, a group organized to oversee campus policies on parking.

Green immediately launched a bold, and ultimately unsuccessful, effort to significantly increase campus parking fees, which had historically been very low. "I think that was the first and last time a student became chair," recalls Marc Fisher, the vice chancellor at the university.

Green ruffled feathers on the city transportation board, too, trying and failing to pass a measure that would have increased taxes to fund buses. By his early 20s he had already reached two positions of real authority, and yet both times he had failed to deliver the jolt to public transportation planning he thought it needed. People wanted cheap parking, and they didn't want their tax money going to improve buses. The convenience of owning and driving a car dwarfed any other consideration, and bus lines and subway stops could never be numerous enough to rival it. But maybe there was a better, different way, outside the public transit system. Green found it on a vacation through Africa, in Zimbabwe.

In Harare, Zimbabwe's traffic-choked capital, he discovered a public transportation system that was more or less the inverse of Santa Barbara's—large private cars took the place

of city buses. The drivers were self-organizing and set their own routes; if more people needed to travel, someone with a car would join the informal bus fleet to add capacity or a new route. "It was a highly efficient free-market solution to their transit problems," Green recalls. This, he thought, could also be the answer to the transit problems that plague Los Angeles and so many other cities. It might offer most of the convenience of traveling by car without the costs of having to own and park one or paying for taxis all the time. When Green returned to the United States, he quit the transportation board and began working on a company that would allow car owners to take part in an American version of what he'd seen in Zimbabwe, becoming self-employed drivers who found passengers through the Internet. Green called his startup Zimride—"Zim" for Zimbabwe.

Green launched Zimride in 2007 with John Zimmer, an analyst at Lehman Brothers he'd met through a mutual friend. The echo of his last name in Zimride at first freaked Zimmer out, but then he took it as a good omen and moved from New York to start work in a tiny shared office in Palo Alto. In the early days, Zimride was simple. A driver would post on Facebook that he or she was going from point A to point B at such-and-such time, and if you were making the same trip you'd reply. These were usually long-range trips between cities, and on average, it took eight messages back and forth before a successful ride took place.

Lyft emerged as a side project within Zimride to provide quick intra-city rides. It started in 2012, when smartphones had become common enough to make the process of matching passengers and riders more or less instant. That same year Uber, which had launched in 2010 but offered only limo rides in higher-end town cars, opened up to ordinary car owners with a service called UberX. Both Lyft and UberX grew fast. In 2013, Green sold Zimride—then operating, among other places, on more than 150 college campuses, and with several hundred thousand users—to the company that owns Enterprise Rent-A-Car. He and Zimmer made Lyft their main project.

It began as a cuddlier Uber. Drivers fixed fluffy pink mustaches to their cars. Passengers were asked to greet their driver with a fist bump before climbing into the front seat, not the back. Otherwise, Lyft functioned like a cut-rate taxi service. Green wanted to differentiate by getting multiple passen-

Green thinks ride-sharing can be cheaper and more convenient than car ownership.
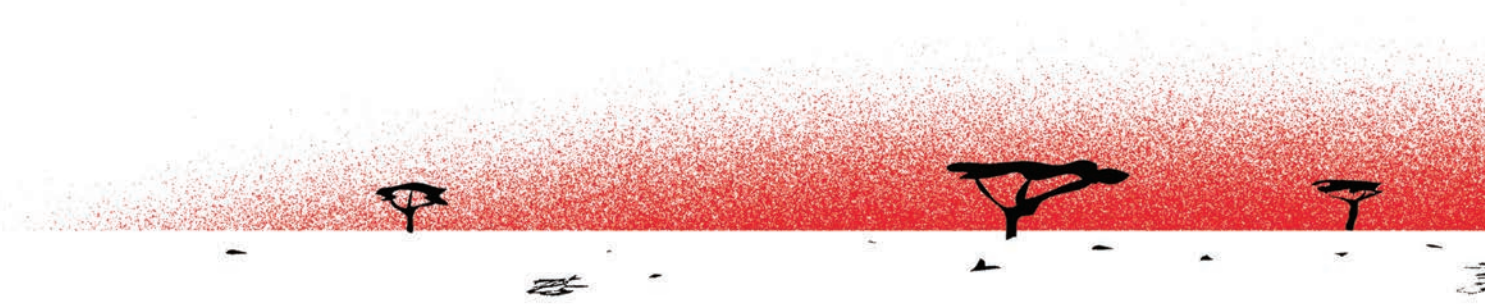
gers into each vehicle, the idea he'd picked up in Zimbabwe, but he found himself preoccupied by what he calls "immediate business issues to solve." One was city and state regulators who tried to block this new, unregulated form of ride-sharing, egged on by entrenched interests like taxi companies. Another was Uber, which was getting hundreds of millions, then billions, in funding, entering new markets with elbows out, and luring drivers away from Lyft. (Several Lyft drivers told me they'd picked up passengers who turned out to be Uber recruiters.) Lyft responded by raising its own war chest and beginning its own pell-mell expansion, albeit only in the U.S.

Today, both rivals have large, growing customer bases. But they both need to figure out a way to turn a profit. Uber seems most focused on using its network of drivers to move more than just people—for example, to deliver packages or takeout orders. Green has shunned that approach. With the Lyft Line option, introduced in 2014, he has chosen a different path— the one he has been on for years. Thanks to the "destinations" feature added not long after, drivers can not only pick up multiple passengers but find riders along the way to somewhere they're already going. Green says this is the start of his new, third form of transport. In some ways it's also very old. Nearly as old as the automobile.

Driver optional

"It's like the jitney," says Juan Matute, associate director of UCLA's Institute of Transportation Studies. "The only innovation is the smartphone, and being tracked in real time. This idea's been around for a century." Jitneys sprang up with the private automobile as a kind of free-market alternative to the streetcar. They ran popular routes, often mirroring those of public streetcars and subways, but for an extra tip drivers would drop you off at your doorstep. Much like Uber and Lyft, they were stunningly, and to some worryingly, popular. In 1915, 62,000 jitneys operated nationwide, and eventually far more people were riding them than streetcars. Streetcar companies successfully lobbied states and the federal government to shut the "jitney menace" down.

Jitneys didn't go extinct: a fleet of vans ply their trade along Brooklyn's Flatbush Avenue, for example. But they survive only by remaining small enough, and far enough under-

Uber vs. Lyft

	Uber	Lyft
Founded	2009	2012
Location	399 cities, 61 countries	66 U.S. cities
Drivers	Hundreds of thousands	Roughly 100,000
Funding	Over $8 billion	$1 billion
Motto	"Everyone's private driver"	"Welcoming, affordable rides in minutes"

ground, not to draw the eye of regulators or the ire of less legally dubious competitors.

Lyft's government relations team is tasked with preventing a similar fate. It's headed by David Estrada, a lawyer who came to Lyft from Google. His strategy is to tell cities that Lyft can help manage their congestion and transportation problems, that it must not be seen and regulated as simply a new variety of taxi service, and that it's at least as safe as cabs and other private car services. He lays out rosy scenarios such as one in which car manufacturers add a dashboard button that transforms you into a Lyft driver with the prod of a finger, making it easy to consolidate the commuters who clog the streets today into fewer vehicles. "That is how simple it should be," Estrada says. "That is what we can achieve. But we are not going to get there if that driver is looked at as a taxi driver."

The San Antonio deal shows that this strategy is not entirely fanciful. Jitneys survive thanks to the widespread gaps between public and private transit, Matute says. Indeed, there is evidence that Lyft customers are spontaneously using the service to fill them. Ever since Lyft Line launched last year, "a really big chunk of rides" have originated from transit stations, says Green. People use

shared Lyft rides to make the crucial transfers between home and station, station and home, that often present a barrier to using public transportation. To capitalize on that trend, late in 2014 Lyft launched Lyft for Work, wherein a business pays the company to get its employees to and from transit stations. The home-rental company Airbnb has tested the scheme to cover the costs of its employees' "last mile" to both the office and their homes, for example. Lyft is also trying to sign up municipalities, colleges, and school systems.

For Lyft to play that kind of role in daily commutes, it must find ways to get as many drivers on the road as possible, with as many people as possible inside each vehicle. Better software for things like scheduling routes is a part of that. Managing the behavior of both drivers and passengers is another. This summer Lyft expanded a program that mentors new drivers to get them on the road faster. And when I joined Green for his weekly meeting with two of his top engineers, one topic of discussion was how to train passengers to tolerate the uncertain wait times that come with putting people going different places in the same vehicle. Lyft is testing the idea of directing people to walk a short distance to a specific spot for a pickup— a kind of smartphone-enabled virtual bus stop. More than a few times, after I summoned a Lyft Line, the driver called me to ask if I could walk a block or two to make for a more efficient pickup. Other times the app would suggest waiting another 10 minutes in exchange for a fare reduction of about a third, buying time until Lyft could put me in a car with as many other riders as possible.

In time, Green believes, some of these human challenges will go away—he thinks autonomous vehicles are inevitable. Google, Uber, and carmakers including Tesla Motors and Audi are spending heavily to develop the technology. But when self-driving cars are finally mature, they will need a killer app. Green argues he will have it ready and waiting, in the form of a system that can efficiently get as many people as possible where they need to go using the vehicles on hand. Whether there's a human in the driver's seat or not, Lyft is the same, he says. "We're the replacement, the alternative, to car ownership." ✚

Ryan Bradley is a journalist in Los Angeles whose work has appeared in Fortune, Popular Science, *and the* New York Times Magazine.

Neurosurgeons hope to treat some of today's most intractable mental disorders by implanting advanced arrays of electrodes into patients' brains.

A Shocking Way to Fix the Brain

By Adam Piore

Photographs by Lauren Lancaster

At right, above, a Parkinson's patient at Mass. General Hospital gets a CT scan before surgery to implant electrodes in his brain. Below, the surgical team awaits the delicate operation.

When Emad Eskandar talks about one of his neurosurgery patients with obsessive compulsive disorder, he's not talking about someone who arranges his record collection by color, size, and name. Or someone who ritualistically touches the knob on the stove twice before leaving the house and says, "Sorry, I'm a little OCD."

Eskandar's OCD patients take three-hour showers. They spend eight hours cleaning their surroundings with bleach. They get stuck at the bathroom sink in their hotel room on appointment days, unable to stop washing their hands until someone comes to get them. OCD affects an estimated 2.5 million adult Americans. But only those who have exhausted all other treatment options—Luvox, Anafranil, Prozac, cognitive behavioral therapy—end up on Eskandar's operating table at Massachusetts General Hospital. By then, they are desperate enough to try almost anything—even deep brain stimulation (DBS), an option of last resort that Eskandar has spent the last 15 years mastering and refining.

In an initial surgery, Eskandar drills two dime-size holes in the top of the patient's skull and sinks 42-centimeter-long electrodes about seven centimeters deep into the gray matter of the brain. In a second surgery, usually a couple of days later, he creates a pocket under the skin in the chest or abdomen, implants a device incorporating a battery and pulse generator into this newly created space, and runs a wire up to the skull, connecting it with the electrodes. When turned on, the device emits an electrical current that stimulates the neural fibers carrying information from primitive brain areas associated with motivation to the frontal lobe. In 50 percent of Eskandar's cases, a miracle follows: the obsessions and compulsions fade and then disappear.

Though the treatment sounds extreme, in some respects his OCD patients are the lucky ones. There is no such FDA-approved last-resort option for the millions of Americans suffering from other psychiatric illnesses, such as depression, post-traumatic stress disorder, or schizophrenia. Or for borderline personality disorder and traumatic brain injuries. But for all these conditions, that may soon change.

Deep brain stimulation has been used for almost two decades to treat patients with severe forms of Parkinson's (and since 2009 to treat a far smaller number of patients with OCD). As many as 125,000 people are living with electrodes implanted in their brains. As part of President Obama's Brain Initiative, Eskandar is co-leading a team of doctors, scientists, and engineers that is one year into a five-year, $30 million effort to use DBS to treat severe psychiatric disorders, most of which have been considered too complex and mysterious for any such system currently on the market. Conditions like schizophrenia, PTSD, and depression are characterized by unpredictable changes in the brain that lead to intermittent episodes. Taming them will require a new kind of device capable not just of stimulating the brain but of monitoring brain

activity in real time and detecting anomalies that, in many cases, neuroscientists have not yet identified.

It will be up to Eskandar, and the team he is leading with his longtime MGH collaborator Darin Dougherty, to identify how the brains of people suffering from these disorders differ from those of healthy individuals. And then they must figure out what kind of electrical stimulation patterns might be used to fix them. "We're aiming for something ridiculously ambitious," he acknowledges.

Engineers across the Charles River at Draper Laboratory are working closely with Eskandar to develop the needed hardware. They have built a prototype of a DBS system that will be able to record signals from hundreds of sites deep in the brain and on its surface. The device will use pattern recognition software to detect anomalous activity associated with pathological mental states; then it will stimulate areas of the brain in response. The Draper engineers are in the process of fabricating a miniaturized version of the device, which they hope to test out in humans as early as 2016.

Most psychiatrists agree that new treatments for mental illness are desperately needed. Existing drugs for brain disorders are often ineffective and frequently produce troublesome side effects. One reason is that drugs alter the chemistry of the entire brain, not just the area of interest, modulating the behavior of otherwise healthy neurons (see "Shining Light on Madness," July/August 2014).

With electrical stimulation, on the other hand, doctors can target discrete populations of neurons, confining the treatment to small, isolated areas of the brain that are causing the problems. "DBS allows us to go into the actual circuit that we know is involved in a condition, and we're stimulating it and making it fire or not fire in the way that we want it to," says Dougherty, the psychiatrist teamed with Eskandar to direct Mass. General's Division of Neurotherapeutics, the nation's busiest center for psychiatric surgical treatment. "It's night and day in terms of the robustness."

To treat brain conditions this way, of course, the surgeons need to identify and understand the precise circuits that cause them—which in many cases has not yet been done. Though neuroscientists have learned a lot about how brain circuits are organized and how they function, it's rarely been possible to watch these circuits operate in real time. But Eskandar and Dougherty say the technology they are designing and testing will open up that possibility. Recording multiple patches of neurons simultaneously for extended periods of time, they believe, will allow them to transform the way we define and understand different types of mental illness—and, more important, finally lead to more effective ways to treat them.

Calming the waters

Physicians have been experimenting with electricity to treat brain disorders since antiquity, in some cases even applying electric ray fish to the skull. But DBS was born in a French operating room in 1987, when a neurosurgeon named Alim-Louis Benabid made a fortuitous discovery while preparing to operate on a patient suffering from uncontrollable trembling.

For decades, the last-gasp technique for such patients had been extreme but often quite effective: brain surgeons simply drilled holes into the skull and removed the areas of the brain thought to be causing the problem. The approach was sometimes used for other movement disorders, as well as severe epilepsy and some mental illnesses. That day in 1987, Benabid planned to remove a piece of his patient's thalamus, a walnut-shaped structure deep in the brain. By destroying or "lesioning" part of the tissue, he intended to cut out the source of the stray electrical impulses flying down the peripheral nerve fibers of the body and causing his patient's hand to shake.

Brain surgery of any sort, of course, is a high-stakes proposition. Miscalculations can cause paralysis, blindness, even death. To avoid surprises, Benabid took a common surgical precaution: he kept his patient awake in the operating room, which is possible because there are no neural pain receptors. He inserted an electrical probe into the part of the brain he intended to remove. Then he delivered a pulse and watched the patient closely to make sure the stimulation had no unanticipated effects. It's a technique neurosurgeons have been using for well over half a century to verify that the area they are about to remove does not serve an essential function; the small current in the electrode causes the neurons around it to fire, revealing what, if any, role they play in bodily processes.

By 1987, neuroscientists had developed a protocol that Benabid fortunately decided to ignore. Instead of stimulating the brain of his patient at a frequency of 50 hertz, he turned the knob up to almost 100 hertz. When he applied the electrode to his target, something unexpected occurred: the patient's hand stopped shaking—for the first time in years. When Benabid turned off the current, the shaking resumed. When he turned it back on, it stopped again. Stimulating at high frequency, he realized, somehow quieted the troublesome signals.

In 1991 he published a paper detailing his use of DBS to treat tremors on both sides of the body. He followed up with another landmark paper demonstrating that he could alleviate many of the other debilitating symptoms of Parkinson's, including slowed movement and muscle rigidity. The U.S. Food and Drug Administration approved DBS for use in tremors in 1997 and for Parkinson's in 2002. It has now been used on tens of thousands of patients.
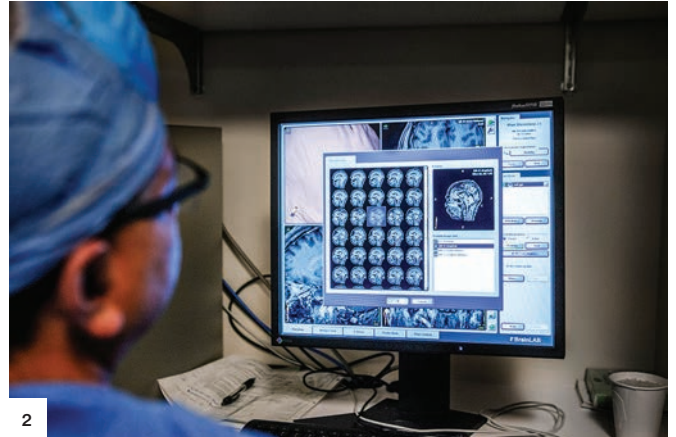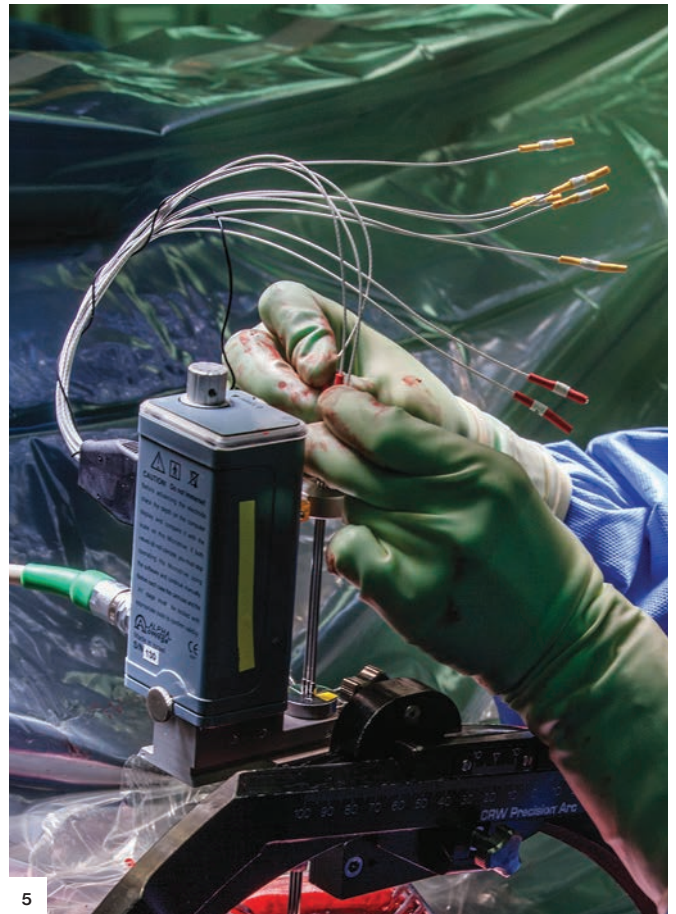
(1,2) The lead surgeon, Emad Eskandar, studies the CT scan of the patient's brain to determine where to place the electrodes. **(3)** He and his team prepare a metal device called a CRW stereotactic frame, which will help guide the process. **(4)** The surgery begins with the drilling of dime-size holes in the skull, through which the electrodes will be inserted. **(5)** Then the surgeon is ready to delicately insert the electrodes into the targeted location in the brain.

Even so, years later, scientists are still debating why DBS works. Scientists had long known that uncontrollable trembling was somehow caused when errant signals emanating from structures deep in the brain continuously activated areas of the motor cortex controlling the body's movements. By the 1980s, they even knew what was causing these signals in Parkinson's—insufficient quantities of a chemical signaling agent called dopamine in structures called the basal ganglia. For decades, however, the organization of the basal ganglia and other features of the brain's inner layers remained largely a matter of speculation.

Benabid theorized that stimulating the neurons suppressed the abnormal activity. Over the last decade or so in animal studies, neuroscientists have more precisely measured neuronal output and found that DBS seems, on the contrary, to stimulate activity. Philip Starr, a neurosurgeon at the University of California, San Francisco, who specializes in move-

extend the technique to treat other brain disorders—in particular, intractable mental illnesses.

Depression

On the day I visit Emad Eskandar's operating room at Mass. General, his patient is laid out on a stretcher wearing a festive dark-blue shade of fingernail polish. The patient is tormented by OCD and has failed to respond to all other treatment options. Now she lies anesthetized amid trays of shiny metallic scalpels and scissors, and the nurses have draped her in a white sheet. They have also shaved her head and, using clamps and screws, secured a sturdy, box-like frame to her forehead and the sides of her skull. Each arm of the frame is etched with the tiny numbers of a ruler, down to the millimeter. The numbers will allow Eskandar to precisely line up the hollow metal leads he plans to press through his patient's cortex and into the center of her brain, following a straight route to his target.
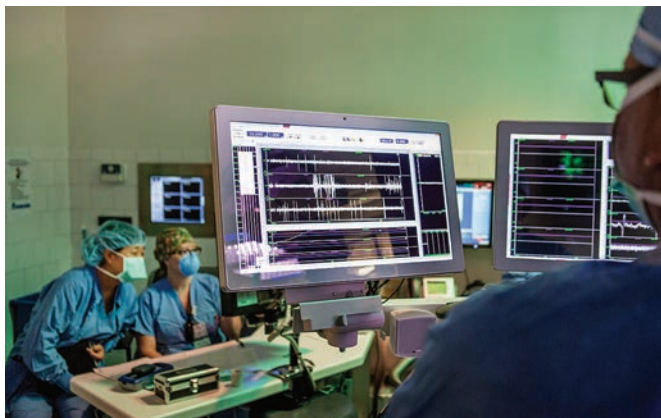
Eskandar's team watches recordings capturing the activity of single neurons in the patient's brain. During the operation, the patient undergoes tests to help map his neural circuits.

ment disorders, has articulated a leading theory: he believes that DBS works by "desynchronizing" firing patterns within circuits.

Just like energy moving through the ocean, electrical signals passing through the brain travel in waves. And as in an ocean storm, a big wave moving at the right speed can subsume all the little waves in its path. In Parkinson's, abnormal activity builds on itself, creating pathological waves of activity that gain control of the circuit, drowning out all other activity. DBS breaks these waves up again, allowing the circuit to unlock and smaller signals to get through.

Whatever the mechanism behind DBS, it was only a matter of time before researchers began to consider how they might

First, however, the neurosurgeon needs to map that route. Eskandar sits nearby in scrubs, a surgical mask rakishly pushed onto his blue surgical cap, and moves a mouse pointer over a spot at the center of one of four images displayed on a monitor, depicting the patient's brain. Each image is taken from a different angle. "This is perfect—you want to be here," he tells a junior surgeon. "That's your entry point."

Eskandar has implanted electrodes in scores of OCD patients; he was among the first neurosurgeons to begin performing the intervention experimentally, long before it was approved for widespread use by the FDA in 2009. It was exactly the type of opportunity he had been hoping for when he decided to attend medical school.

He had excelled at math and physics in high school and entered the University of Nebraska intent on becoming a chemical engineer. But that changed when he got a night job working in a psychiatric institution, supervising patients experiencing acute psychotic breaks. The patients he met made a profound impression. There was the mathematics professor with a PhD from Northwestern, hopelessly confused by his own delusions. Eskandar also recalls a disheveled guy his own age, who heard voices in Van Halen songs and once hopped the fence during an outdoor recreation period when Eskandar wasn't paying attention. The police found the patient a couple of hours later, standing in the middle of the freeway directing traffic with a fork.

Eskandar was fascinated by the magnitude of these delusions and amazed by how little doctors understood about mental illness. "It was a very different feel than a regular hospital," he recalls. "It was like, 'Does anybody really know what's going on?'" He applied to medical school hoping to unlock the mysteries of the brain. After a stint doing brain research at the National Institutes of Health, he earned a residency at Mass. General Hospital just as the FDA was approving the first use of deep brain stimulation for movement disorders. Having entertained and kept watch over patients with brain disorders just a few years earlier, he now found himself operating on them, and in the process he got the opportunity to measure their neural activity and join the hunt for the causes of such bizarre behavior. He stayed at Mass. General after his residency ended.

Now, Eskandar is standing over the OCD patient's naked scalp, marking his entry points with a Sharpie. Then he snaps an attachment onto the metal frame encasing the patient's head, adjusts the angle to line up the numbers, and lets the assemblage of nurses, residents, and other observers know he is ready. Within a few minutes, he has opened up two boreholes in the patient's skull and used the head rig to pilot two long, hollow metal tubes down through the outer layers of her brain and into the middle of the gray matter. Into the tubes he slides a pair of thin electrodes that will be connected to the device he plans to implant later. Then he removes the tubes, stitches the electrode leads into the scalp using silk threads, and fills the boreholes with fast-setting cement.

The device to be implanted in the patient's body is effective at treating OCD. But it uses technology that has been around for decades, and the veteran neurosurgeon is certain that he and other clinicians have only scratched the surface of what might be possible once today's technologies upgrade the DBS systems available in the operating room. "Think about what's happened over the past 20 years in terms of miniaturization and Moore's Law and everything," Eskandar says. "You have

this device that came out in the '90s. When it was designed in the 1980s, I didn't even have a cell phone."

The new system being developed at Draper, which Eskandar and his Mass. General colleagues helped design, will be able to gather data from as many as 320 electrodes—including multiple groups of sensors placed on the outer layer of the brain—and deliver stimulation accordingly. Instead of a bulky processor implanted in a patient's chest or abdomen, the device will consist of a miniaturized central hub, smaller than a cell phone, with an integrated battery. The whole thing will be compact enough to fit snugly on the back of the skull. The skull hub will attach to as many as five ceramic and titanium electronic satellites that are small enough to fit into dime-size burr holes drilled into the top of the skull. Each of these satellites will collect and relay the data from the electrodes that will be connected to the sensors or the leads deep in the brain. The team has also created a remote base station that communicates wirelessly with the skull hub; it can recharge the hub's battery and analyze the data it has stored over the course of the day.

The new device, with its multiple leads and sensors, could be key if Eskandar and his colleagues are to extend the technology to depression and other, more complicated mental disorders. In the mid-2000s, he and Dougherty won approval to conduct a trial that used DBS to treat depression. The results, in some cases, were remarkable, hinting at the potential the team is now attempting to realize. But in many other cases, the treatment was frustratingly ineffective. A more advanced device could mean far more precise interventions tailored to individual patients and, perhaps, an effective treatment for a larger group of people.

Their first patient had tried all the medications that science had to offer, not to mention 30 rounds of electroconvulsive therapy. Her name was Liss Murphy, and by the time she met Dougherty in 2006, she was desperate. A couple of years earlier, she had been a dynamic, 30-something PR executive living in Chicago. But depression had incapacitated her in a matter of weeks, leaving her hardly able to speak. One day she left work and never went back. Forced to move home to the Boston area in 2004, she ended up at McLean Hospital.

After Eskandar operated on Murphy, she began an astonishing recovery. She was able to resume her relationships with friends and family. She had a son, and experienced happiness, laughter, and joy again for the first time in years. The power of the approach was driven home to her in 2012, when an infection required doctors to shut off Murphy's device for several months. Within days, her depression returned; but when the device was turned back on, she says, she experienced a powerful physical transformation.

"It was just a surge of warmth that rises through you, and I could tell it was on," she says. "I woke up the day after and it was a whole new world. The colors outside were brighter. My son and I went to the story hour. It had been months since just he and I had done anything. Everything was new again, and it was like I made it to the other side."

Inspired, Dougherty and Eskandar expanded their trials and saw similar results with a number of other patients (though certainly not all). By then, a parallel effort to use DBS against depression was already under way. In March 2003, Helen Mayberg, a neurologist then at the University of Toronto, had implanted a DBS device into a patient with depression, placing it in a narrow band of a brain structure called the subgenual cingulate. She published a paper in the journal *Neuron* in 2005, a year before Murphy's operation, reporting results in six subjects (she followed that up with a group of 20, who are still being followed today). Like Murphy, some of them had been virtually catatonic before the surgery but recovered.

Mayberg's initial success with DBS, along with the work of Eskandar and Dougherty's group, fed the expectation that the device would soon win FDA approval for a condition affecting millions of Americans. Both groups had somewhere around a 50 percent response rate, with remission in a third of the cases, according to Dougherty. But the large trials the FDA mandated before the treatment could be approved required control groups to measure placebo effects. Experimenters implanted DBS devices in all the volunteers; then they randomly assigned half to a standard protocol of stimulation and the other half to a protocol in which the electrode is never turned on. After analyzing preliminary results, the FDA halted both trials. "We ended up having a fairly high placebo effect," Dougherty says. "But it definitely worked in some people."

Eskandar and Dougherty have seen too many remarkable recoveries to discount the treatment. Mayberg also remains a staunch believer in the power of DBS to treat depression. All three, however, believe that a more sophisticated DBS system of the sort Draper is developing is likely to make the therapy more effective. The reason is simple: the problems that occur in depression and other psychological disorders are not confined to one anatomical location. They are diseases of neural circuits and usually present complex arrays of symptoms, which might vary depending on which part or parts of the circuit are affected. This means there are different varieties of depression, and different varieties of patients with depression; each person might respond differently depending on where, when, and how the brain is stimulated.

In recent years, Mayberg has begun to map the complex connections radiating out from the spot she targets in DBS, a region called area 25. Working backwards, she hopes to reverse-engineer the circuit and identify all its hubs and component parts. With a more complex device capable of sensing and stimulating in multiple areas, she believes, it might be more feasible to tailor interventions to different subjects, adapting stimulation patterns to their specific symptoms and neural activation patterns.

Eskandar and Dougherty, meanwhile, have even broader ambitions. They hope to develop therapies for a whole host of other mental conditions so complex that treating them with the current generation of crude, one-directional devices would be virtually unimaginable.

Telltale colors

Sitting in Eskandar's lab, I watch a rotating 3-D image of a translucent skull and the brain within it. Within the black-and-white brain, distinct neural activation patterns are highlighted in three different colors: turquoise, orange, and magenta. To create the images, Eskandar's colleagues used functional magnetic resonance imaging (fMRI), a technique that tracks changes in neural activity by measuring blood flow to different areas of the brain. The turquoise represents the brain activation patterns recorded from a healthy subject as he performed a specific task. The orange and magenta represent the activation patterns recorded from the brains of two psychiatric patients as they performed the same task. All three patterns appear different. Although the orange and magenta patients have both been diagnosed with major depression, each has an additional condition: one is suffering from PTSD and the other has generalized anxiety disorder.

"These disorders, by very definition, are constellations of symptoms," Dougherty says. Which is why, he argues, a more precise treatment, better tailored for individual patients, could make all the difference. "There is no depression spot," he says. "There is no PTSD spot. There is no borderline personality disorder spot."

Using the DBS system that's currently available, Eskandar explains as he points at the two depressed patients' brain patterns, the treatment strategy would be simply to turn on an electrode and stimulate the same area of the brain for both patients. The advanced DBS system Dougherty and Eskandar are developing with Draper, in contrast, will be able to sense abnormal patterns of brain activity in real time and stimulate whichever areas are affected. They should adjust when new patterns crop up, applying a jolt of electricity in the right spot each time.

Eskandar once again calls my attention to the screen. The three brain scans we are looking at, he tells me, were

A member of the surgical team evaluates the patient with the implanted DBS electrode, assessing the benefits and any side effects of the procedure.

all recorded while the patients performed a task that measured their ability to quiet the emotional areas of the brain and answer a question that required focus and mental clarity. Eskandar points to one of the depressed patients' brain activation patterns, explaining that it is the same pattern one usually finds in patients experiencing symptoms of PTSD. The emotion-driven part of the brain called the amygdala is alight with activity. It is firing far more robustly than the amygdalas of normal patients performing this same task. It's as if the emotional part of this patient's brain is screaming, drowning everything else out.

Imagine, Eskandar suggests, if we could simply override this reaction, manually activating and deactivating the appropriate areas. In fact, he has already attempted to demonstrate just that in a patient who had electrodes implanted in preparation for surgery to treat epilepsy (neurosurgeons often use this technique to monitor activity and verify the precise location from which seizures are originating). Eskandar and his team could turn up the patient's emotional response to a picture of a human face by stimulating the amygdala, and they were able to blunt that response by stimulating a different area, the dorsal anterior cingulate cortex.

The team hopes to design a whole host of new DBS treatments: the device's electrodes will be inserted at locations chosen according to each person's constellation of symptoms, and the particular abnormalities in the brain circuits will determine where the current will be activated. Eskandar is optimistic about the prospects for treating depression with these new tools. He also has high hopes for treating PTSD and generalized anxiety disorder. He even feels good about the possibilities for treating addiction, schizophrenia, and traumatic brain injury. But he acknowledges that some of the conditions he and Dougherty plan to target, such as borderline personality disorder, remain long shots. Even in the one psychiatric disorder for which DBS is FDA-approved, OCD, the success rate still hovers around 50 percent—a stark reminder of the challenges that lie ahead.

Indeed, Eskandar and Dougherty are under no illusions. The human brain remains one of the most enigmatic and complex biological systems known. And in many ways our efforts to understand it are still in their infancy. By the end of this year, Eskandar says, he hopes to demonstrate that the new system can be programmed to sense a specific pattern of brain activity and respond to it. It's a relatively simple test of the technology. Even so, success is not assured. "I'm sure it's not going to work the first time, or probably even the third time," he says. "But eventually it's going to work. And we'll keep trying until we get it right." ◼

Adam Piore is a freelance journalist based in New York.

MIT Technology Review
BUSINESS REPORT

The Future of Work

Technology is changing the nature of the jobs we do and the way we do them. What does that mean for the future of work?

JOSH COCHRAN

63

The Big Question

Work in Transition

Digital technologies are changing the nature of the jobs we do. What does that mean for the future of work?

● About five years ago, machine learning reached a point where software could, with guidance from senior lawyers, effectively take over the time-intensive task of legal discovery, in which one party in a lawsuit combs through its documents to determine what it must show to the other side before trial.

This is a job that junior lawyers, paralegals, or—increasingly—less expensive contract lawyers had traditionally done, and some fretted that the change might be just the first step in the computerization of the law. But while machine learning does well with structured tasks like searching for relevant words, handling documents similar to others already identified, and even reconstructing simple summaries of a baseball game, it is far less adept at constructing something like a legal memo, where persuasiveness can rely on developing novel arguments, explains economist Frank Levy, an MIT professor emeritus who, with Dana Remus, a professor at the University of North Carolina School of Law, is researching computers' impact on the practice of law.

"There's much less structure in a legal memo, which is trying to figure out a strategic approach to an argument," says Levy, who coauthored (with Harvard professor Richard Murnane) an influential book, *The New Division of Labor,* about how computers are changing employment and the job market. Adds Levy: "You are putting a premium on innovation."

It's likely that work done by humans will increasingly involve innovative thinking, flexibility, creativity, and social skills, the things machines don't do well. In a recent study on automation from the University of Oxford, researchers tried to quantify how likely jobs are to be computerized by evaluating how much creativity, social intelligence, and dexterity they involve. Choreographers, elementary school teachers, and psychiatric social workers are probably safe, according to that analysis, while telemarketers and tax preparers are more likely to be replaced.

Most professions won't go the way of the telemarketer, but the work involved is likely to migrate toward the tasks humans are uniquely skilled at, with automation taking over tasks that are rules-based and predictable.

How jobs are evolving in this new model of work is the big question this report seeks to examine.

In addition to affecting the type of work we do, digital and mobile technologies are changing how we do it, where we do it (at home or remotely), and who our competition is. At Upwork, a platform that connects freelancers with jobs, 50 percent of corporate customers are based in the United States, but only 20 percent of the workers are. Opening up a global talent competition could make it harder to earn high wages.

A growing number of platforms like Upwork, TaskRabbit, Uber, Airbnb, and others that connect freelancers to clients are creating a new type of labor market, something consultant Sangeet Paul Choudary calls "networked work." In this world, workers are responsible for their own development and assume many of the risks employers once bore. They depend on the platform for business, but they also have the ability to develop a reputation based on client satisfaction.

This networked model is disruptive enough to have led to riots in Tianjin, China, where taxi drivers are fighting the arrival of Uber and the bite it has taken out of their income. The people who drive for Uber are largely part-timers looking to make a little extra money. Uber customers in China take nearly one million rides a day, the company says, and management is investing more than $1.1 billion to expand into 100 more cities this year. The job of driving cars has not gone away, but the way that work is done is changing, and the transition is not painless.

Tim O'Reilly, CEO of O'Reilly Media, has recently been writing about how tech-

Hot Jobs

Some of the jobs expected to grow fastest in the U.S. over the next seven years

	Number of jobs, 2012	Median pay, 2012	Rate of growth, 2012–2022**	Likelihood of being automated
INDUSTRIAL-ORGANIZATIONAL PSYCHOLOGIST	160,200	$69,280	53%	low
DIAGNOSTIC MEDICAL SONOGRAPHER	110,400	$60,350	46%	medium
GENETIC COUNSELOR	2,100	$56,800	41%	unavailable
PHYSICIAN'S ASSISTANT	86,700	$90,930	38%	low
INFORMATION SECURITY ANALYST	75,100	$86,170	37%	low
OCCUPATIONAL THERAPY AIDE	38,600	$48,940	36%	low
MEDICAL SECRETARY	3,947,100*	$35,330*	36%	high
PHYSICAL THERAPIST	204,200	$79,860	36%	low

nology can both create new types of jobs and improve the quality of work. Mobile and sensor technologies could support health workers and help elderly people stay in their homes, for example, while machine learning could help doctors make decisions.

Some jobs will surely be automated out of existence, but technology has the potential to create new jobs as well.

—*Nanette Byrnes*

Data Analysis

Where the Tech Jobs Are

Expanding supplies of data and cheap processing power will drive demand for IT specialists in a broad range of fields.

● Jobs in science, technology, engineering, and math (STEM) overpopulate the U.S. Labor Department list of occupations expected to grow the most through 2022: among the 580 occupations the department tracks, they make up 14 of the 35 fastest-growing.

Fewer than half the available jobs in categories like data science and programming are in technology industries as traditionally defined, according to the job-hunting site Glassdoor. The rest are in a range of fields that are benefiting from the falling cost of data storage and the increase in processing speeds that

....
Job growth in fields like computer-directed stock trading and electronic medical records is being driven by expanding pools of data that can be crunched economically.
....

allows data to be crunched economically, says Andrew Chamberlain, Glassdoor's chief economist—fields like computer-directed stock trading, electronic medical records, and even more mature industrial sectors. On Glassdoor, which aggregates job postings from across the Internet, there were recently listings

for almost 13,000 software engineers, 1,568 data scientists, 1,691 programmer analysts, and 4,033 database administrators. (Overall, the U.S. economy is adding about 230,000 jobs a month.) Depending on the job title, 60 percent to 75 percent were at non-IT companies, Chamberlain says.

Regulatory changes have also increased the focus on data. The Dodd-Frank law imposes new reporting requirements on banks. The Affordable Care Act is driving hospitals and independent doctors toward quality management and measurement programs that depend on computing. With the population aging, the U.S. government predicts that 62 percent of new STEM jobs added through 2022 will be in health care. Partners HealthCare in Boston has hired more than 600 IT professionals to implement its new electronic medical records system.

In energy, another increasingly data-intensive field, predictive analytics software run on a massive scale recommends where to drill and how much water to use in each well. Even fields that were once the sole domain of humanities majors, like advertising, are hunting for technologists today. At the Austin ad agency T3, CEO Gay Gaddis is currently looking for user-experience designers, Android developers, and data analysts.

Over the next decade, the Bureau of Labor Statistics projects, the ranks of genetic counselors, market research analysts, and information security analysts will grow by 30 percent or more. Jobs in civil and petroleum engineering will grow at the same 20 to 29 percent rate as systems analysts, and health-care reform, which seeks to have more work done by workers who make less money than doctors, will help increase employment of physician's assistants and nurse practitioners by 30 percent or more.

"Across STEM, very few fields are declining," says Bureau of Labor Statistics economist Michael Wolf.

Salaries and demand are both rising fast. A UCLA analysis of 2013 data published this June contended that the average tech worker in San Mateo County, which

....
13,000
Number of recent listings for software engineers on Glassdoor
....

includes Facebook's Menlo Park headquarters, is making more than $300,000. The unemployment rate in San Francisco is 3.5 percent. STEM jobs today pay almost double the average wage in the economy as a whole, says economist Sophia Koropeckyj, a managing director at Moody's Analytics: "The high compensation of these jobs gives them an outsize role in promoting economic growth." —*Tim Mullaney*

Venture Capital

On the Edge of Automation

Five hundred years from now, says venture capitalist Steve Jurvetson, less than 10 percent of people on the planet will be doing paid work. And next year?

● As a founding partner at the venture capital firm Draper Fisher Jurvetson and a board member at SpaceX and Tesla Motors, Steve Jurvetson spends a lot of time thinking about the future, often the distant future. One of Elon Musk's biggest backers—Jurvetson boasts that he owns the first Tesla production Model S—he was also a founding investor in Hotmail, the precursor to Microsoft Outlook, and sits on the board of Craig Venter's Synthetic Genomics, the constructor of the first synthetic cell.

His firm claims to have funded companies that have created more than 20,000 jobs in the past five years, and to have

brought nearly two dozen companies to $1 billion in value before exiting. Jurvetson spoke to Business Reports senior editor Nanette Byrnes about why he thinks 90 percent of people will be unemployed in 500 years and how we might transition to that sharply different future.

Are today's new digital technologies destroying or creating jobs?
I absolutely believe in the near to medium term there is going to be net job creation, as there always has been. Think of all the Uber jobs. The opportunity is not yet fully tapped to, in a sense, distribute [over the Internet] the service economy. The service economy is bigger than the goods economy, so the online equivalent should be even bigger and more powerful than the online marketplace for physical goods.

> **"Five hundred years from now, everyone is going to be involved in some kind of information or entertainment ... There will be no farmers, there will be no people working in manufacturing."**

Many of these new jobs, including those at Uber, are taking shape on what you call the "edge of automation." Do you fear that these jobs might quickly disappear as technology keeps evolving?
Everything about Uber has been automated except for the driver. The billing, the fetching—every part of it is a modern, information-centric company. Interestingly, what that means is as soon as automated vehicles arrive, that driver is easily removed. You don't have to restructure any part of that business.

What you're farming out to humans today are those things that computers just barely can't do. We know from Moore's Law and improvements in computing that in two or three years [much of this] work will be automated.

If a startup or new business venture has created a job that involves human labor, it probably has done so in a way that is pretty marginal. Whether you're a technology enthusiast or a detractor, the rate at which this will shift is probably going to be unprecedented. There will be massive dislocation.

Which jobs will survive?
In the long run, 500 years from now, everyone is going to be involved in some kind of information or entertainment. Nobody on the planet in 500 years will do a physically repetitive thing for a living. There will be no farmers, there will be no people working in manufacturing. To me it is an impossibility that people would do that. People might do it for fun. You might have an organic garden in your backyard because you love it. Five hundred years from now I don't know if even 10 percent of people on the planet have a job in the sense of being paid to do something.

It's hard to imagine what that life would be like.
It pretty much will be what life was like for most of human history—just without the gruesome servitude. The concept of a "job" is pretty recent. If you go back a few hundred years, everyone was either a slave or a serf, or living off slave or serf labor to pursue science or philosophy or art. We'll live off the production of robots, free to be the next Aristotle or Plato or Newton. Unless we're miserable without doing busy work.

Is there some way, some government policies or strategies, to minimize the pain of such a dramatic shift?
I don't think that anyone in Washington is going to get their head around this and make meaningful change. No politician has a 50-year horizon. I see zero chance that long-term thinking will govern policy.

The knock on Silicon Valley today is that it's not taking on big problems either.
I do lament how many investors focus on all the short-term sugar buzz of some marginal improvement in something— nothing history books are ever going to be written about. In many cases these are quick and easy ways to make money. I do think there are more and more entrepre-

neurs all the time that think big. Those are the people we should be finding and funding. Most of them will fail, but the ones who succeed will change the world, and that is progress.

Data Analysis

The Measured Worker

The technology that illuminates worker productivity and value also contributes to wage inequality, Tyler Cowen argues.

● Discussions of income inequality typically focus on how information technology raises the return to skilled labor, or on the rise of global trade, or perhaps on the way that politics skews power toward the rich and well-connected. But there's another fundamental driver of income inequality: the improved measurement of worker performance. As we get better at measuring who produces what, the pay gap between those who make more and those who make less grows.

Consider journalism. In the "good old days," no one knew how many people were reading an article like this one, or an individual columnist. Today a digital media company knows exactly how many people are reading which articles for how long, and also whether they click through to other links. The exactness and the transparency offered by information technology allow us to measure value fairly precisely.

The result is that many journalists turn out to be not so valuable at all. Their wages fall or they lose their jobs, while the superstar journalists attract more Web traffic and become their own global brands. Some even start their own media companies, as did Nate Silver at FiveThirtyEight and Ezra Klein at Vox. In this case better measurement boosts income inequality more or less permanently.

In any organization or division many colleagues do good work, but only so many would be truly difficult to replace.

And those are the people who, with better measurement of economic value, receive higher salaries and bonuses.

Imagine a situation where a group of workers produces some output collectively. The tendency is to resort to equal pay scales, perhaps with some inequality built in for seniority and other highly visible characteristics, such as working overtime. Relatively equal pay structures help build group solidarity, and in the meantime the superior producers cannot easily demonstrate their worth to other potential employers because no publicly observable measurements capture that added value.

But as information about productivity improves, the better workers demand more and can get it; in fact, bosses will want to offer more to preëmpt them from leaving. Workers also stop thinking of themselves as bringing the same value to the table, and that can make inegalitarian pay structures less damaging to morale and thus more attractive.

One unfortunate possibility, or shall I say likelihood, is that some workers may not produce much of anything at all. They may be major shirkers, or perhaps they are smart and talented workers who nonetheless are poison for workplace morale. Their office scheming takes away more than their labor adds. These "zero marginal product" workers, as I have labeled them elsewhere, may have a hard time holding down a job. In the modern world it is harder for them to hide behind the labor of others.

Insofar as workers type at a computer, everything they do is logged, recorded, and measured. Surveillance of workers continues to increase, and statistical analysis of large data sets makes it increasingly easy to evaluate individual productivity, even if the employer has a fairly noisy data set about what is going on in the workplace.

This analysis, if only in crude forms, starts when workers are applying for a job. A significant percentage of bosses in America look up an employee's credit score before making a hiring decision. Some employers are even using performance in online video games to evaluate individual talent. There are also Facebook, Twitter, LinkedIn, and numerous other social-media outlets, all of which do give us some clues about character, effort, and the quality of a person's social connections. It's not hard to imagine a future where an individual's eBay and Uber ratings, among other pieces of information, are up for sale in the marketplace. The more reliable job candidates might disclose such information voluntarily. Over time schools may offer more information about their students than just GPAs and letters of recommendation, as statistical analysis improves in its ability to assess their potential.

Looking further ahead, and more speculatively, employers might request genetic information from workers. Anyone who doesn't want to turn it over might be seen as having something to hide, and thus this information will spread even if you may feel that our society doesn't want to tolerate genetic discrimination. Or perhaps the information can be lifted from a doorknob or from a cup of coffee during an interview visit. It's hard to imagine that this valuable source of information will stay confidential forever, given that most databases have proved hackable.

This explanation for growing inequality has some potentially distressing features, but also some upside.

The upside, quite simply, is that measuring value tends to boost productivity, as has been the case since the very beginning of management science. We're simply able to do it much better now, and so employers can assign the most productive workers to the most suitable tasks. Workplace incentives can also be more closely geared to the actual production of value for the enterprise.

The downsides are several. Individuals don't in fact enjoy being evaluated all the time, especially when the results are not always stellar: for most people, one piece of negative feedback outweighs five pieces of positive feedback. To the extent that measurement raises income inequality, perhaps it makes relations among the workers tenser and less friendly. Life under a meritocracy can be a little tough, unfriendly, and discouraging, especially for
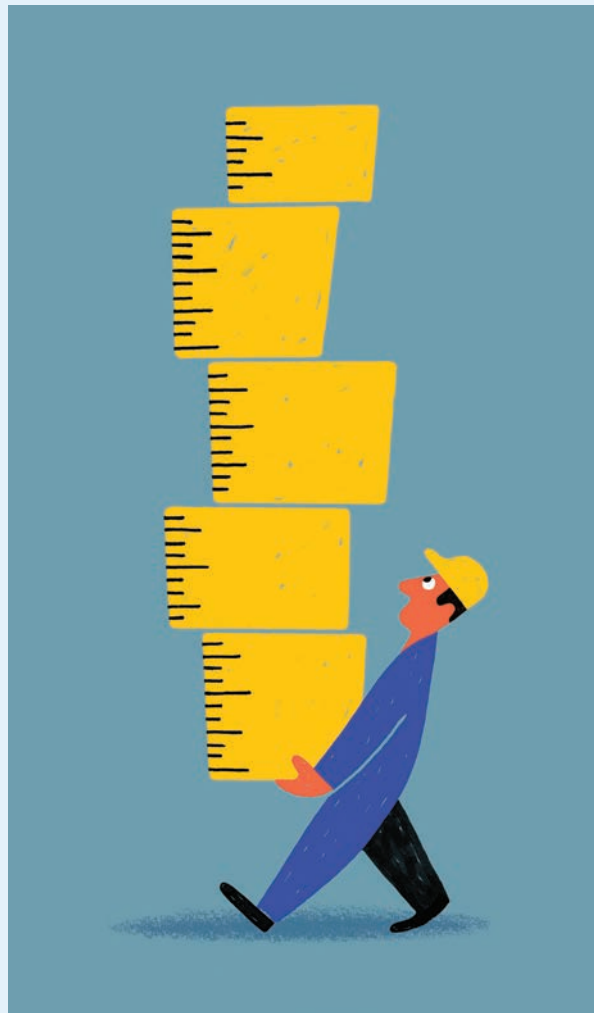
those whose morale is easily damaged. Privacy in this world will be harder to come by, and perhaps "second chances" will be more difficult to find, given the permanence of electronic data. We may end up favoring "goody two-shoes" personality types who were on the straight and narrow from their earliest years and disfavor those who rebelled at young ages, even if those people might end up being more creative later on.

That said, measurement of worker value isn't going away anytime soon. The real question is not whether we want it or not, but how to make it better rather than worse. Ideally we'd have a system where individuals can correct measurement errors in their records to prevent injustice and preserve accuracy. We'd also like a system where individuals are not tracked and segmented too early, where outsiders and immigrants receive a fair hearing, where risk taking is rewarded rather than punished, and where some degree of privacy, including privacy in the workplace, remains.

Obviously, that is a tall order.

I wonder, by the way, if *MIT Technology Review* will tell me how many people clicked on this article. —*Tyler Cowen*

The author is a professor of economics at George Mason University.

Mobile Apps

Uber's Bumpy Ride in China

Chinese Uber drivers are making a million trips a day, pleasing consumers but threatening traditional taxi drivers.

● Mornings at 5, Mr. Dong, a manager at a livestock farming company in Tianjin, logs in to his Uber account. Before he heads off for work at 7, he can make three to four trips around the city center in his Buick. After he leaves his office at 6 P.M., he continues driving until 9 P.M. On weekend mornings, he's in such high demand that he can complete as many as 10 trips before noon.

"Right now a lot of people are using these services," says Mr. Dong, 38, who gave only his last name to avoid jeopardizing his full-time job. On top of covering his monthly gas money of about 1,000 yuan ($156), he can earn between 800 yuan ($125) and 1,000 yuan every month by driving for Uber.

In China, private Uber drivers are making almost a million trips per day, according to the CEO of Uber. Less than two years after its launch here, Uber has developed a fierce rivalry with the homegrown Didi Kuaidi, which reports that its daily private-car requests have tripled to three million since May, and engendered resentment among traditional taxi drivers.

Chinese cities in some ways seem ripe for a technology-driven transportation overhaul. The roads are jammed. According to government figures, there were almost 126 million private vehicles in China at the end of 2014, a 15.5 percent increase from the previous year. The 2014 TomTom Traffic Index shows that a third of the 50 most congested cities in the world are in China. Other commuting options are painful, too—during rush hours a rider in the Beijing subway has to wait for several loaded trains to pass before squeezing in.

The Chinese State Council has identified transportation as one of the traditional industries whose efficiency could be improved by online platforms, but Uber remains in a legal gray area. Its drivers are considered private car operators and do not pay all the registration fees, value-added tax, and income taxes traditional cabbies do. Uber drivers say they often avoid places where there are a lot of police officers, such as airports and train stations. If they are caught, the fines can be as high as 10,000 yuan ($1,564). Recently speculation has increased that online taxi reservations will become a regulated business.

Uber's not waiting. With the newly set up UberChina, the ride-hailing service plans to expand into 100 Chinese cities, at least half with a population over five million, in the next year. (It currently operates in 11 cities, including Tianjin, with an average population of 14 million.) The company also plans to invest more than seven billion yuan ($1.1 billion) in China in 2015.

Drivers of China's 1.37 million traditional taxis are already reacting. In May, dozens of cabbies blocked the roads

---

Uber is in a legal gray area. Speculation has increased that regulation of online taxi reservations may be coming.

---

around the Olympic stadium in Tianjin with their cars and lured private-car drivers to the area using ride-hailing apps. As soon as they arrived, the two groups started fighting.

"I'm a bit dispirited," says Lu Lifang, 48, a traditional taxi driver. "If the government doesn't regulate the private cars, my profession will disappear sooner or later." She and her fellow cabbies also complain about dwindling income. Wang Hongyong, 47, says he earns about 150 yuan ($23) less per day now than he did in 2014. "I'm also more tired," he says. "I don't rest in between."

1,000,000
Number of trips being made daily by Uber drivers in China

Driving is not a livelihood for most Uber drivers. Most, like Mr. Dong, drive for extra cash. Xing Gao, who works at an insurance company in Tianjin, hasn't picked up any calls on his Uber app since June because the company has dropped to nearly zero the subsidy it was paying him for each completed trip. In 2014, he had a guaranteed 30 yuan ($5) subsidy per trip. "They want to test the bottom line of drivers," says Xing, 32, "just to see how much lower they can go before you quit." —*Yiting Sun*

## HIRED AND FIRED BY ALGORITHM

The cycle of how we find, keep, and lose jobs is increasingly affected by algorithms. Here are some of the data-mining companies aiming to take the "human" out of "human resources." By Julia Sklar
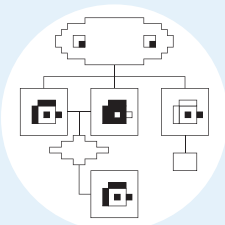
Step 1
Finding job candidates
Seattle-based **Textio**, whose clients include Microsoft, evaluates job postings to predict if they're likely to attract the right candidate. For example, phrases such as "top tier" and "mission critical" tend to turn female candidates off. San Francisco–based **Gild** sifts data from sites like LinkedIn and Github to tell customers such as Facebook and HBO when candidates might be open to a new post. **KF4D**, an algorithm from headhunter Korn Ferry, calculates the characteristics of an effective leader in a given industry and location, a model employers can then compare candidates against.
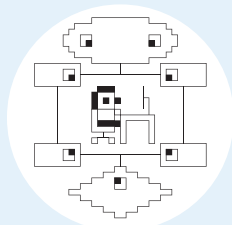
Step 2
Tracking employees
Following billions of dollars in fines for misconduct in recent years, many Wall Street firms have begun closely tracking workers. The goal: to both catch and forecast bad behavior. **J. P. Morgan** has designed a system to use data about things like whether individuals attend compliance classes to feed its predictive models of employee behavior, part of a $730 million overhaul of its management system. Goldman Sachs and Credit Suisse are investors in **Digital Reasoning System**, which analyzes billions of employee e-mails, phone calls, and online chats to predict and prevent illegal behavior.
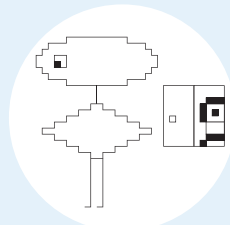
Step 3
Quitting
According to **Visier**, a workforce analytics group based in San Jose, California, unwanted employee turnover costs the average large company $31 million a year. Visier uses two to three years' worth of data from client companies like Yahoo, ConAgra, and Nissan to build predictive models that it says are up to eight times better than human intuition at forecasting which employees are at risk of quitting within three months. Each employee's risk score is based on factors like age, salary, department, and time since last promotion. The company manages data for over two million employees.
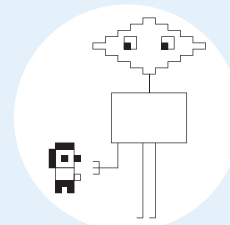
Step 4
Finding the next job
Seattle-based **Anthology** (formerly known as Poachable) is like a dating app for the business world: employees looking for a change and businesses looking to hire each provide anonymous information about what they are looking for. A direct line of communication opens between users and businesses only if their interests match. Barely a year old, Anthology has clients that include Amazon, Facebook, IBM, and Netflix. Some 50,000 job seekers are using the app for free. Anthology has raised $1.8 million in funding.

Tools

Aging Workers, New Technology

The number of workers over 65 is growing fast. Technologists see a big business in helping the aging workforce.

● The American tradition of retirement at age 65 is crumbling. As older workers stay on the job longer, challenges ranging from eyestrain to aching joints become increasingly prevalent. In response, technologists and ergonomics experts are rethinking working conditions.

As recently as 1992, less than 3 percent of the American workforce consisted of people age 65 and over. Today that proportion has nearly doubled, according to the U.S. Bureau of Labor Statistics, and it's expected to reach 8.3 percent by 2022. Most of these 13.5 million older workers will be between 65 and 74, but nearly 2.6 million will be 75 and over.

One reason for this demographic shift is improved longevity. American men who reach 65 can expect to live another 17.9 years on average, the National Center for Health Statistics calculates, while women can count on 20.5 years. Both figures are up more than a third from the norms of the 1950s. With so much life still ahead, high-status workers may not want to be idle, while low-paid workers often find that meager savings won't let them quit. At the same time, thanks to the service sector's steady ascendancy over manufacturing, many jobs require less physical stamina.

While it's easier to wield a stapler than a rivet gun at age 70, some aspects of office

life can still vex people beyond a certain age. "Many products are designed with younger users in mind," says Sara Czaja, scientific director of the Center on Aging at the University of Miami. "Designers don't always think about older people."

Consider smartphones' tiny screens. Office workers who frequently text or check their news feeds and e-mail may switch between near and far vision 100 or more times a day, say researchers at Germany's Carl Zeiss Vision, a leading manufacturer of eyeglass lenses. That's a particular strain for older workers with a diminished ability to focus on nearby objects, a condition that typically begins between ages 40 and 50 and then gets steadily worse.

To minimize digital eyestrain, Zeiss shifts the reading area in its progressive lenses higher and closer to the eyes, taking into account the position in which people hold their smartphones.

Another challenge: the eyes of 60-year-olds take in only about a third as much light as those of 20-year-olds, because their pupils are smaller and their lenses cloudier. That necessitates brighter office lighting, with as few shadows and dark spots as possible, says Ryan Anderson, director of product and portfolio strategy at Herman Miller, the office furniture maker based in Zeeland, Michigan. It's not enough to blast more lumens onto people's desktops; minimizing shadows and dark zones is just as crucial. That has led to new types of overhead lighting fixtures that bounce most of their light off the ceiling for optimal dispersion, rather than aiming directly below.

Older workers also often need more back support, Anderson says, which creates problems if sustained use of laptops or tablets tempts people to lean forward at their desks. One Herman Miller solution: a desk with a sliding surface that can be drawn nearer to the user, making it possible to sit upright and rest against a chair back while using a mobile device at close range.

At Florida State University, Neil Charness, director of the Institute for Successful Longevity, has taken an interest in the challenges that using a computer mouse can present for older workers. "I've been studying aging for a long time," he says, "and now, at age 67, I've become one of the people I study." He is glad that many operating systems can be set to allow programs and documents to be activated by single-clicking; double-clicking can be harder for older users. He reduces his own need to scroll down with a mouse by turning his computer monitor sideways; eye movements tend to be easier for older adults than hand movements.

Microsoft has for years provided an online "Guide for Individuals with Age-Related Impairments," showing older workers how to create slower-moving pointers or magnified screen displays by adjusting their computer's settings. Now Ai Squared, based in Manchester, Vermont, has developed software for people with macular degeneration, a condition predominantly affecting older people, in which a deteriorating retina causes vision loss in the center of the visual field. Its technology can transform display colors so that people who have trouble with black type on a white background might see their e-mail and Web pages as yellow type on a black background, which is often easier to read. "One gentleman uses our software to make everything purple on a pink background," says Ai Squared marketing project manager Megan Long. "That's what works best for him."

For older workers who stand—rather than sit—on the job, specialized floor pads better balance the load on ankles, knees, and hips. These "anti-fatigue mats" have been common since the 1980s, but inventors keep refining the concept. One version, with arrays of hollow rubber cylinders fused in place under the mat's surface to provide a mild springiness, was patented in 2009. Hospitals are major buyers. The average age of U.S. nurses climbed to 50 in 2013, according to the National Council of State Boards of Nursing, up from about 47 in 2004.

A broad array of technologies that are being developed to help those with disabilities could also end up helping other people work longer. Boeing, for example, has a project to help travelers glide through airports on a driverless cart, and Carnegie Mellon is working on robot escorts for those with limited vision. The U.S. Department of Transportation has begun an "accessible transportation" initiative to help people with limited mobility, including older workers. Aaron Steinfeld, a Carnegie Mellon researcher, is helping to develop Tiramisu Transit, a crowdsourced system that can share real-time information about where buses are and which are relatively full or empty. Such data "can be very important for those with balance issues or who use wheelchairs or scooters," Steinfeld says.

—George Anders

Swelling Ranks of Older Workers

By 2022, more than 8 percent of the U.S. workforce will be 65 or older.

Age: ■ 55–64　■ 65–74　□ 75+
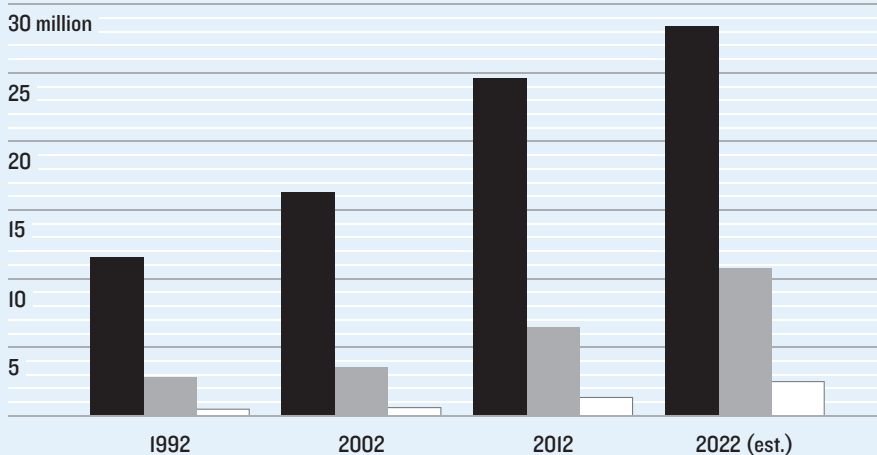
Computation and Data Science

Technology Jobs: Radiology

Digitization didn't gut the field, and recent innovations are expanding radiology beyond interpreting images.

● Radiology can date its birth to December 22, 1895, when the German physicist Wilhelm Röntgen shot electromagnetic radiation through his wife's left hand to produce the world's first human radiograph, a black-and-white image of a skeletal hand wearing a wedding ring.

In recent years, the transition from analog to digital imaging and advances in computer-based medical tools have allowed radiologists to access imaging results on a mobile phone or tablet and analyze them immediately. Now, new tools—designed to help radiologists deal with a rapidly growing amount of data and make faster, more accurate diagnoses—are changing the job in other unexpected ways.

Asked what a radiologist does, most people are likely to think of a physician sitting alone in a dark lab reading x-rays, says Moritz Wildgruber, a radiologist and researcher at the Klinikum Rechts der Isar hospital in Munich, Germany. At one time digital imaging technology seemed like a potential threat to the profession. Some feared that with "teleradiology," radiographs could be efficiently sent off-site to be read assembly-line-style.

As with many technological shifts, the reality has been more tempered. In part because of strict regulations and liability issues limiting where a scan can be read and by whom, radiology has not been outsourced wholesale. On-site hospital radiology groups remain important, though teleradiology is used in remote areas and in overnight urgent care.

Technologies beyond digitization, however, have become increasingly important to radiology. Among them are computational medicine and data science.

New applications can reconstruct a tumor in 3-D and precisely measure its volume as it changes over time. "As a radiologist you cannot just stick to the images anymore; you have to be able to use this software," says Wildgruber. "Otherwise you can't deal with the workload."

The increasing complexity of the work and the sheer volume of medical images, which now include video recordings and digital models, have created new challenges, and new opportunities, for companies like IBM and Germany's Brainlab. "A typical emergency room radiologist will do 30 to 40 CT studies, with 2,000 to 3,000 images per study," says Tanveer Syeda-Mahmood, chief scientist for a project at IBM that is developing automated radiology and cardiology tools. "You're easily looking at 100,000 images per day." With all this data—images for one patient might account for 250 gigabytes, says Syeda-Mahmood—a radiologist is at risk of missing the small percentage of images crucial to identifying pathologies.

IBM, which developed the Watson technology that triumphed on *Jeopardy!*, is testing whether similar computer-based reasoning, machine learning, and analytical problem solving modeled on human cognition could ameliorate some of these issues. According to the company, early work has demonstrated that the system can autonomously learn what a pathology looks like—say, an abnormal narrowing in a coronary artery—and automatically alert the radiologist to the most important images for a given patient.

The system is still learning, but Syeda-Mahmood says that in testing it has achieved over 80 percent accuracy with certain medical conditions—in the range of a good radiologist. Its education could be sped up by having it study the 30 billion images from hospitals, pharmaceutical companies, and clinical research organizations that the company recently acquired in its $1 billion purchase of Merge Healthcare.

Though Brainlab, whose major markets include North America, is working from a different angle, it too could greatly alter radiology by better utilizing imaging—both diagnostic and interventional—in the operating room.

A neurosurgeon working in an operating room outfitted with Brainlab's image-guided surgery and intraoperative CT systems—like those at the Klinikum Grosshadern, in Munich—is able to visualize tools, anatomy, and radiologic images of diseases overlaid, in real time through a neurosurgeon's scope, on the patient's brain. At the same time, the radiologist can watch live feeds of the surgery in person or remotely, review images and video taken at various stages of the operation, and coördinate treatment.

These technological advances enable radiologists and other physicians to perform more kinds of treatments, including minimally invasive techniques like recanalization of blocked blood vessels and targeted tumor therapies carried out under image guidance.

This blurring of medical portfolios has begun to create conflicts between once-distinct medical specialties. "If you want to open an occluded artery with a stent," says Wildgruber, "the radiologist can do it, the vascular surgeon can do it, the cardiologist can do it." So whom do you go to when you arrive at the hospital for such a treatment? Today the answer, surprisingly, may come down to which department is available when you walk in.

—*Russ Juskalian*

▸ **ACCESS THE FULL REPORT ONLINE**

Additional stories explore the technologies connecting freelancers to work, investigate jobs of the future, and take a look at how the sharing economy is creating new careers.

New Technologies Fuel Freelancing

Airbnb's "Super Hosts"

Networked Work

Outside Reading

Upcoming Events

technologyreview.com/business

Reviews

Fighting ISIS Online

The Islamic State is an Internet phenomenon as much as a military one. Counteracting it will require better tactics on the battlefield of social media.

By David Talbot

The two men pecked out messages on opposite sides of the country. "Yes the Islamic State was a fantasy in 2004, now look at it. The U.S. was a fantasy in 1776, now look at it," the man in Virginia wrote in a Twitter direct message to an online friend in Oregon. The Virginian, who went by various Twitter handles, including one with "Jihadi" in it, had been obsessively watching slick online videos produced by the Islamic State, also known as ISIS: brutality and jihadist propaganda, much of it translated into English and other languages. Now he was talking about traveling to Syria and forming a militia in Virginia. "Washington beat an empire with 3 percent of the population. I can do it with 1 percent."

His correspondent in Oregon was Paul Dietrich, a programmer and digital activist joining jihad-related Twitter conversations out of curiosity. Alarmed, he did what relatively few are doing: he tried to intervene with someone who was showing signs of being radicalized by ISIS's social-media campaign. Dietrich heard the man's grievances sympathetically, tried to talk common sense, and suggested he get psychological help.

Then one night he called the Virginia man "stupid."

"How am I stupid?" he responded.

"Let me count the ways. You are a jihadist, in America, who wants to start a militia, and you think you'll win," Dietrich wrote. "Stop. This. Madness. While. You. Can."

The Virginia man was, at least, talking. "I'll think about it."

Extremist groups have long used the Internet, and citizens have long left home to fight for their countries' enemies. But ISIS stands apart in the way it's mastered online propaganda and recruitment. Using 21st-century technology to promote a medieval ideology involving mass killings, torture, rape, enslavement, and destruction of antiquities, ISIS has been the prime mover among Islamist groups that have lured 25,000 foreigners to fight in Syria and Iraq, including 4,500 from Europe and North America, according to a U.S. government report released in September. "The ISIS social-media campaign is a fundamental game changer in terms of mobilizing people to an extremist cause," says Amarnath Amarasingam, a researcher at the University of Water-

One to One Online Interventions: A Pilot CVE Methodology
Institute for Strategic Dialogue, London
September 2015

The ISIS Twitter Census: Defining and Describing the Population of ISIS Supporters on Twitter
Brookings Institution
March 2015

The Call-Up: The Roots of a Resilient and Persistent Jihadist Presence on Twitter
University of Vienna
November 2014

The Islamic State
Soufan Group
November 2014

JAVIER JAÉN

loo who is co-directing a study of Western fighters in Syria. "You are seeing foreign fighters from 80 or 90 countries. In terms of numbers and diversity, it has been quite stunning." As Google's policy director, Victoria Grand, told a conference in Europe in June: "ISIS is having a viral moment on social media, and the countervailing viewpoints are nowhere near strong enough to oppose them."

Indeed, the technological response to stanching the recruitment isn't having much of an effect. Internet companies close accounts and delete gory videos; they share information with law enforcement. Government agencies tweet out countermessages and fund general outreach efforts in Muslim communities. Various NGOs train religious and community leaders in how to rebut ISIS messaging, and they create websites with peaceful interpretations of the Quran. But what's missing is a widespread effort to establish one-on-one contact online with the people who are absorbing content from ISIS and other extremist groups and becoming radicalized.

Humera Khan, executive director of Muflehun (Arabic for "those who will be successful"), a Washington, D.C., think tank devoted to fighting Islamic extremism, says people like her and Dietrich who try such online interventions face daunting math. "The ones who are doing these engagements number only in the tens. That is not sufficient. Just looking at ISIS-supporting social-media accounts—those numbers are several orders of magnitude larger," says Khan. "In terms of recruiting, ISIS is one of the loudest voices. Their message is sexy, and there is very little effective response out there. Most of the government response isn't interactive. It's a one-way broadcast, not a dialogue."

Reversing the tide will require, among other things, much more of what Khan and Dietrich have done. What's needed is better ways to identify the people most at

ISIS fighters and supporters are steeped in the vernacular of secular online culture. Just like other people their age, they tweet cat photos and pictures of their meals.

risk of being persuaded by extremist messages and more reliable ways to communicate with them. As an example, a London think tank called the Institute for Strategic Dialogue recently piloted experiments in which it found people at risk of radicalization on Facebook and tried to steer 160 of them away. It was a small test, but it shows what a comprehensive peer-to-peer strategy against extremism could look like.

Distribution mechanisms
ISIS differs from previous radical Islamic movements. For one thing, it forged important alliances to capture territory. After merging al-Qaeda factions with elements of Saddam Hussein's military and intelligence agencies, it seized two major cities, Raqqa in Syria and Mosul in Iraq—a region with more than six million inhabitants (at least before the latest mass migrations), substantial resources of oil, water, and wheat, and institutions such as universities. Al-Qaeda, in contrast, never controlled more than a few pockets of territory in such places as Somalia and Yemen. "Never before had a jihadist movement gained the kind of territory and wealth that might allow them to function like states and run public relations campaigns," says Nico Prucha, a researcher at the University of Vienna and a fellow at the International Center for the Study of Radicalization at King's College London.

Second, ISIS differs ideologically from other jihadist groups. A few days after ISIS grabbed Mosul in 2014, a stern-faced, black-robed man ascended stone steps in a mosque and claimed the grandest title of them all: "Caliph," leader of all Muslims, successor to the Prophet Muhammad, with aims to unite Muslim lands into a caliphate much like the ones that rose and fell in the first millennium. The man was Abu Bakr al-Baghdadi, ISIS's leader. He had cleverly attached his extremist cause to a larger idea that resonates with many Muslims: the restoration of the caliphate.

"Really, you are dealing with a social movement in the true sense—it's no longer just 'a group' that people are joining," says Mubin Shaikh, a former extremist in Toronto. He has worked undercover for Canadian intelligence services on several investigations, one of which involved infiltrating the "Toronto 18," a group of young Muslims charged with planning terror attacks in 2006. Today, he also advises U.S. counterterrorism agencies and tries to intervene online to stop young people in Toronto's Muslim community—the largest in North America—from becoming radicalized.

"People will make analogies to fighters joining the Spanish Civil War," Shaikh says. "While I understand the analogy, I don't think it applies. This is really peculiar to the Muslim context. The Muslim world—especially the young Muslim world—has been psychologically primed

for a long time to the idea of reëstablishing the caliphate. It's this idea that Muslims are living under humiliation, and the only time we were not is when there was a caliph. It really is an idea of reclaiming lost glory."

Third, ISIS emerged after important technological shifts. Think back to when terrorists made their first beheading video, in 2004. According to the CIA, this grainy and gruesome piece of media likely shows Abu Musab al-Zarqawi (the leader of al-Qaeda's branch in Iraq, which later morphed into ISIS's predecessor) slaughtering Nick Berg, a radio entrepreneur from Pennsylvania. It was a laborious task to upload this file onto a jihadist Web forum. There was no YouTube or Twitter to allow instant sharing of videos or links to them. Facebook was still a dorm-room plaything. Few people had smartphones. Al-Qaeda used news organizations such as

Al Jazeera to release its videos and statements. Today, however, affordable devices, fast networks, and abundant social-media accounts directly feed a spectacularly large potential audience of young people. A recent study found that the world's 1.6 billion Muslims have a median age of 23.

The notional head of ISIS's media operations is a 36-year-old Syrian named Abu Amr al-Shami, who had been the ISIS boss in Aleppo, according to the Soufan Group, a consultancy whose leaders include former U.S. and U.K. counterterrorism officials. The propaganda effort includes a slick online magazine called *Dabiq*. And there's a division called Al Hayat Media, which targets Western audiences. It's run by a German rapper formerly known as Deso Dogg who now calls himself Abu Talha al-Almani, according to the Middle East Media Research Institute. His oeuvre includes recruitment videos, called Mujatweets, in which you might see fighters handing out ice cream to children.

But the larger social-media campaign is aided by sympathizers in the Middle East, North Africa, and elsewhere who produce their own content in multiple languages. This decentralized approach makes it hard to go after the people producing it. "They can do this anonymously from wherever they live," says J. M. Berger, a nonresident fellow in the Project on U.S. Relations with the Islamic World at the Brookings Institution and coauthor of a paper called "The ISIS Twitter Census."

The propaganda consists of more than graphic videos; it adroitly addresses national, local, and tribal grievances. For example, on February 3, videos surfaced of ISIS soldiers forcing a captured Jordanian fighter pilot, Moaz al-Kasasbeh, into a metal cage—and then burning him to death. Western media reports focused on the deed's barbarity, but the fire starts 18 minutes into the video. The bulk of it lays out a detailed argument for the act, making connections between President

ISIS propaganda targets a youthful audience by referring to popular video games such as Call of Duty; riffing on Internet slang like YOLO ("you only live once"); and mimicking Hollywood production styles.

75
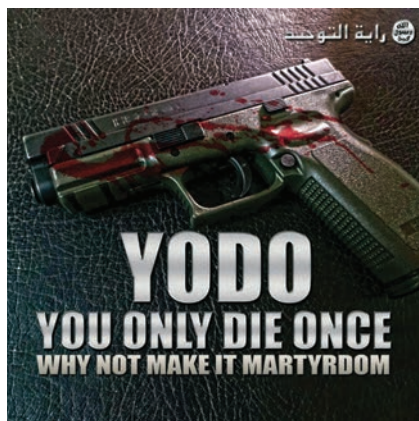
Obama and Jordanian leaders; between American-made armaments and Jordanian air strikes on ISIS; and between those air strikes and the dead and bloodied on the ground in Raqqa. Under the logic of "an eye for an eye," ISIS had a justification for the fighter pilot's execution, and the act had a clear political goal as well, Prucha explains. It was designed to drive a wedge between King Abdullah of Jordan, who is close to al-Kasasbeh's uncle, and the many refugees from such airstrikes who are living in the country. For good measure, the text was translated into French, English, and Russian.

The propaganda put out by *Dabiq*, the ISIS magazine, includes articles geared to certain audience segments. Recruitment pitches for women, for instance, emphasize themes of sisterhood and belonging—and highlight the role of marriage and family in bolstering "Brand Caliphate," as Sasha Havlicek, founder of the Institute for Strategic Dialogue, puts it. As potential recruits are wooed, ISIS supporters engage them in one-on-one chats that are often steered to all-encrypted channels.

In trying to understand why ISIS is so adept at all this, one comes back to a simple explanation. The people doing it grew up using the tools. "When you say 'terrorist use of social media,' it sounds ominous, but when you look at it as 'youth use of social media,' it becomes easier to understand," says Khan. "Of course they are using social media! They are doing the same thing youth are doing everywhere."

Scaling up

As he pulls up to meet me at the Toronto City Airport in his cluttered Dodge Caravan, Shaikh, with his gray-flecked pencil sideburns, looks like the 40-year-old, minivan-driving father of five that he is. Two decades ago, however, he was a disaffected, hard-partying Toronto punk who latched onto Islamic extremism. So he understands ISIS's target audience today.

Tweets from the ISIS front lines

"I just noticed our martyred brother r.a. had a tumblr (I know, how could I have missed it). Make sure to check it out"

"This Syrian guy next 2 me (AbuUbaydah) is so stoked for our op he almost shot his foot off. Come on bro – safety 1st. :p"

"I have never met brothers who want death so badly as much as these brothers. All they want to do is meet their lord, is that such a crime?"

"Ya Allah when it's my time to go have mercy on my soul have mercy on my bros"

"Kurdish sniper with us, his two sisters are with the YJP. He was so happy when he got notified one was killed. One to go."

"Brothers, come to Jihad and you will taste a certain taste of eeman you have you have been missing out on. Tastes good. Hayya 'alal Jihad!"

"Put the chicken wings down n come to jihad bro."

And like Dietrich and Khan, he sometimes tries to tackle the exhausting task of engaging online.

At one point, to attract possible extremist followers, he created a Twitter username, "@CaliphateCop" (he later deleted it, but now the name is used by another Twitter user), and included a quote from the Quran in his profile. He would jump into Twitter conversations and soon engaged with many people professing support for extremist causes. One was, Shaikh says, an al-Qaeda supporter in Syria. "How can you sleep at night knowing Muslims are in prison due to your snitching?" the Syrian wrote. Shaikh shot back: "How can U claim any sort of Islam and accept the random killing of civilians? Where the heck did U learn your religion?"

"Allah Al Musta-an!!" (roughly equivalent to "Oh my God!") came the reply. "Canada participated in the destruction of the Islamic emirate, they have no innocents for their crime."

Shaikh countered: "Really? Random people walking2work who hav zero attachment2 what govt does—they're legit targets?"

The Syrian had his rationalization ready: "Who was the first person in Islam to use the catapult? It was the prophet. And we both know the catapult doesn't only hit enemy combatants."

Social-media research has shown that messages from friends and peers are more persuasive than general advertising. Other bodies of research show that youth at risk of falling into many kinds of trouble, from drugs to gangs, often benefit from even small interventions by parents, mentors, or peers.

But so far, major anti-ISIS programs don't involve that kinds of outreach. For example, over the summer the British government launched a tweet campaign to broadcast government messages against ISIS. Some $188 million from U.S. government agencies funds anti-extremist projects and other community-engagement programs around the world, including one aimed at stanching recruitment inside prisons. And there are efforts to develop new social technologies. Affinis Labs, based in Arlington, Virginia, describes itself as a Y Combinator–like incubator for Muslim-centric apps. One is "QuickFiqh," in which youths ask 60-second questions about Islamic law and get 60-second answers from mainstream Islamic scholars, made to be easily shared on social media. But these efforts are aimed at Muslims more generally and don't specifically target people showing signs of becoming radicalized.

Shaikh and others doing peer-to-peer work say they're frustrated because they can't know whether the people they talk

to online are the ones most at risk or are too far gone and thus a waste of effort. They also want more evidence about what approaches and messages are most effective. So this year the Institute for Strategic Dialogue decided to develop a systematic peer-to-peer anti-extremism strategy. First the group recruited 10 former extremists (five from far-right groups, five from jihadist groups) to serve as "interveners." Next, they used a Facebook feature called Graph Search to find people whose interests, pages liked, group memberships, and other indicators showed they were likely to be moving toward extremism. The interveners winnowed the list to 160 people and used a little-known "pay per message" feature (you can pay $1 to send a message to a stranger) to start a dialogue. The preliminary results showed that most recipients responded, a crucial first step. Some 60 percent started a "sustained engagement" when the initial overture was nonjudgmental and empathetic.

The study pointed, in a crude way, to what might be possible at a larger scale. "Social media has assisted extremist causes, but there are many ways for us to push back using the same tools," says Ross Frenett, who led the study. "We just haven't optimized that. We haven't pursued that."

Today, ISIS still dominates in the online struggle. Young people continue to leave Western countries for the battle zone. But every now and then, there are small victories. Khan and Dietrich say the young man in Virginia is seeking mental health treatment. Though known to the FBI, he has not been charged with any crime. Having started down the path of radicalization, he may be on his way back because of a few people talking to him online, one on one.

David Talbot is senior writer at MIT Technology Review *and a fellow at the Berkman Center for Internet and Society at Harvard University.*
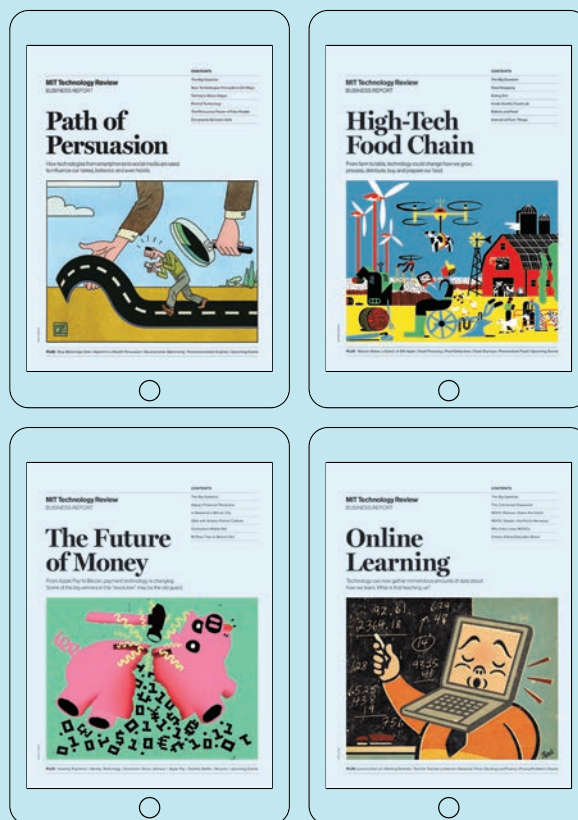
The Hit Charade

An algorithm might create a playlist you enjoy, but don't mistake that for creativity.

By Will Knight

Zane Lowe's first show as a DJ on Apple Music was a bit dizzying. The songs he played lurched from punk-pop to post-rock to grime to electronica to stadium rock and beyond. He showcased previously unheard songs along with tracks recorded decades ago by well-known rockers. Yet despite the disarray—or probably because of it—I enjoyed the show. Each new track took me in a surprising direction, while the mix of artists and the energy of the songs seemed to match Lowe's slightly deranged chatter.

One thing that stands out about Apple Music, a streaming service you can use on computers and mobile devices for $10 a month, is the presence of human DJs like Lowe on a channel called Beats 1. Lowe's show introduced me to unfamiliar artists, and it highlighted intriguing musical connections—between, say, a stadium anthem by AC/DC and a recent piece of remixed electronica by a Scottish artist called Hudson Mohawke. The emotion running through all the songs was upbeat, even defiant.

Just as computers cannot yet create powerful and imaginative art or prose, they cannot truly appreciate music. And arranging a poignant or compelling music playlist takes a type of insight they don't have—the ability to find similarities in musical elements and to get the emotional resonance and cultural context of songs. For all the progress being made in artificial intelligence, machines are still hopelessly unimaginative and predictable. This is why Apple has hired hundreds of people to serve as DJs and playlist makers, in addition to the algorithmic recommendations it still offers.

Bringing in human experts is a clever way for Apple to differentiate itself. Despite hav-

JACOB ESCOBEDO

ing pioneered the digital distribution and storage of music, it now finds itself lagging behind streaming services such as Pandora, Spotify, Rdio, and Tidal. None of these emphasize curation by human experts as much as Apple Music does. And while the algorithms that all these companies use for recommending songs have improved greatly in recent years, there's no real musical understanding or appreciation going on. It shows. The algorithms employ statistical techniques to parse listener data, making an educated guess as to what you might like. There is still no algorithm that can account for human taste.

Hearing things

Pandora, one of the first music streaming services, is a good example of the algorithmic approach. Through a decade-old effort called the Music Genome Project, Pandora has employed music experts to tag songs with hundreds of characteristics, such as the genre, the types of instruments used, and even the melodic phrasing and tonality. When you give Pandora a band, composer, or song as a starting point, it creates a "radio station" of music with similar attributes. Choose the Beatles, and Pandora may automatically cue up a song by the Beach Boys, informing you, "We're playing this track because it features mellow rock instrumentation, demanding vocal performances, interweaving vocal harmony, mixed minor & major key tonality, and melodic songwriting."

Sadly, Pandora's choices tend to be rather predictable—often just as bland and conventional as those on commercial radio. After beginning with the Beatles, you're unlikely to hear a song in a very different style that was popular around the same time, for example, or a hip-hop artist

Apple Music

Pandora

Spotify

"Creativity, the Turing Test, and the (Better) Lovelace Test"
By Selmer Bringsjord, Paul Bello, and David Ferrucci
Mind and Machines, vol. 11, 2001

who's done a clever job sampling the work of Ringo and co.

More recently, algorithms have begun producing playlists that can feel a lot more nuanced and tailor-made. The world's biggest streaming service, Spotify, which has more than 75 million users, is pushing the state of the art, using vast amounts of data to make personalized recommendations.

Chris Johnson, who leads one of Spotify's data science teams in New York, says the company does employ humans to make some of its playlists. But it also collects as much data as possible on a user's listening behavior, and then compares it with data collected from other users. The idea behind this technique, known as collaborative filtering, is that you'll probably like a song that someone with similar tastes has already

discovered and enjoyed. Last year, Spotify acquired a company called the Echo Nest that gathers information about new music posted to blogs, news websites, and social media. These opinions also now feed into Spotify's recommendations, helping to make its music suggestions cleverer still.

In July, Spotify began testing a personalized playlist made available this way. "We look at what you're playing, playlists you're creating, and basically everything we know about you. From that, every Monday, there's going to be this new playlist of music," Johnson told me.

The first few playlists I received included several songs that I instantly loved, though none stray very far beyond the stuff I already listen to. It's useful, but not quite mind-blowing.

There is an inherent limitation to such automated recommendation algorithms, too: they cannot suggest a new song, because there's no data to show how much other listeners like it. In contrast to an algorithm, humans can usually tell, within a few moments of listening, just how much they like a new track. Here, though, recent advances in artificial intelligence are starting to help. Last year, Spotify began testing a way of analyzing a song itself rather than just the metadata associated with it. This involved training what's known as a deep-learning network, roughly modeled on layers of neurons in the brain, to recognize frequency features of an audio signal (corresponding to the sound you hear and the way that sound changes over time) in millions of songs. These algorithms can classify a new song surprisingly well, as shown in example playlists posted by a member of Johnson's team at Spotify.

But even this feat is not evidence of real musical understanding or judgment. Spotify's deep-learning system still has to be trained using millions of example songs, and it would be perplexed by a bold new style of music. What's more, such algorithms cannot arrange songs in a creative way. Nor can they distinguish between a truly original piece and yet another me-too imitation of a popular sound. Johnson acknowledges this limitation, and he says human expertise will remain a key part of Spotify's algorithms for the foreseeable future.

Apple's Beats 1 offers a vastly different experience. One radio show, *The Alligator Hour*, which is fronted by the musician and producer Joshua Homme, celebrates obscure but extremely original songs. It also revels in the absurd connections that can be found between some songs—pairing, for instance, the melodic side of the Sex Pistols with the adrenaline that fuels Donna Summer's disco. It's delightfully weird. In another show, called *Mixtape Delivery Service*, the musician Annie Clark (stage name St. Vincent) plays a

custom list of songs inspired by one listener's mood or situation. In her first show, Clark arranged a retrospective of less well known but culturally significant dance music for an 11-year-old girl who wanted to learn more about the genre.

Auditory Turing test

What is it that gives people this ability? Could deep learning or other artificial-intelligence systems ever develop "taste" that goes beyond classifying the characteristics of a song to determine whether it is "good" or not? Might computers be able to identify that intangible quality that people naturally associate with talent or creativity or originality? When I asked Johnson if an algorithm might someday be able to scout out a hit song from an unsigned artist, he said: "That's exactly what we want to do."

It's a bold ambition, and one that might prove elusive. Musical appreciation and creativity have nothing to do with finding statistical patterns in great piles of data.

"What differentiates something unusual or bizarre from something creative? That's a difficult question," says Eyal Reingold, a psychologist at the University of Toronto who studies human creativity. For a machine to demonstrate creativity, he says, "it would have to produce something that's not only unusual—or something that's not been programmed into it—but that is judged to be useful, at least in some cultural context."

Indeed, the slippery nature of creativity has led some psychologists and computer scientists to suggest that it could be a useful way to measure machine intelligence. In a paper published in 2001, two academics from Rensselaer Polytechnic Institute, together with David Ferrucci, then an IBM researcher who would go on to create a computer called Watson that would win the game show *Jeopardy!*, argued that a creativity test could be a better way to judge whether a computer had achieved human-

type intelligence. They noted that the test proposed in 1950 by Alan Turing, which gauges a machine's intelligence through a typed conversation, encourages programmers to employ trickery rather than build something genuinely intelligent. They reasoned that feats of creativity, whether in painting, writing, music, or some other field, are much harder to fake and are fundamental to intelligence. And they called their alternative the Lovelace test, after Ada Lovelace, often considered the world's first computer programmer, who noted in 1843 that the first computing machines, impressive though they might be, would be incapable of doing anything original.

Tellingly, efforts to pass the Lovelace test have largely foundered. Still, the challenge lives on. In fact, Michael Casey, a professor of music and computer science at Dartmouth College, plans to hold several Turing tests early next year, perhaps followed by some Lovelace tests. One will involve computer DJs, with dancers asked to judge whether the songs they just heard were cued up by a human or by a machine. Casey hopes that within this limited context, a machine will demonstrate something akin to musical creativity.

He hardly seems confident, though. "No matter what type of algorithm we've tried to apply in the past to music—whether it's something that tries to mimic Bach or Mozart, or tries to recommend music—at a certain point it feels like it doesn't have any 'shape' to it," he says, a little ruefully. "It may, for a few seconds, fool you, but it doesn't have an overall plan. And I think the same may be true of an automated DJ set."

Perhaps this will be true for a long while yet. And if we want machines to come up with something as unique and original as a show on Apple's Beats 1, then we might need to think a little more creatively about how we design them.

Will Knight is senior editor for AI.

SXSW® INTERACTIVE 2016

MARCH 11–15
AUSTIN, TX

CREATIVITY
DISCOVERY
INSPIRATION

"SXSW Interactive has become a go-to conference for emerging technologies and a key event to jump-start new business relationships and ventures." *– Forbes*

Next Discount Registration Deadline: November 20

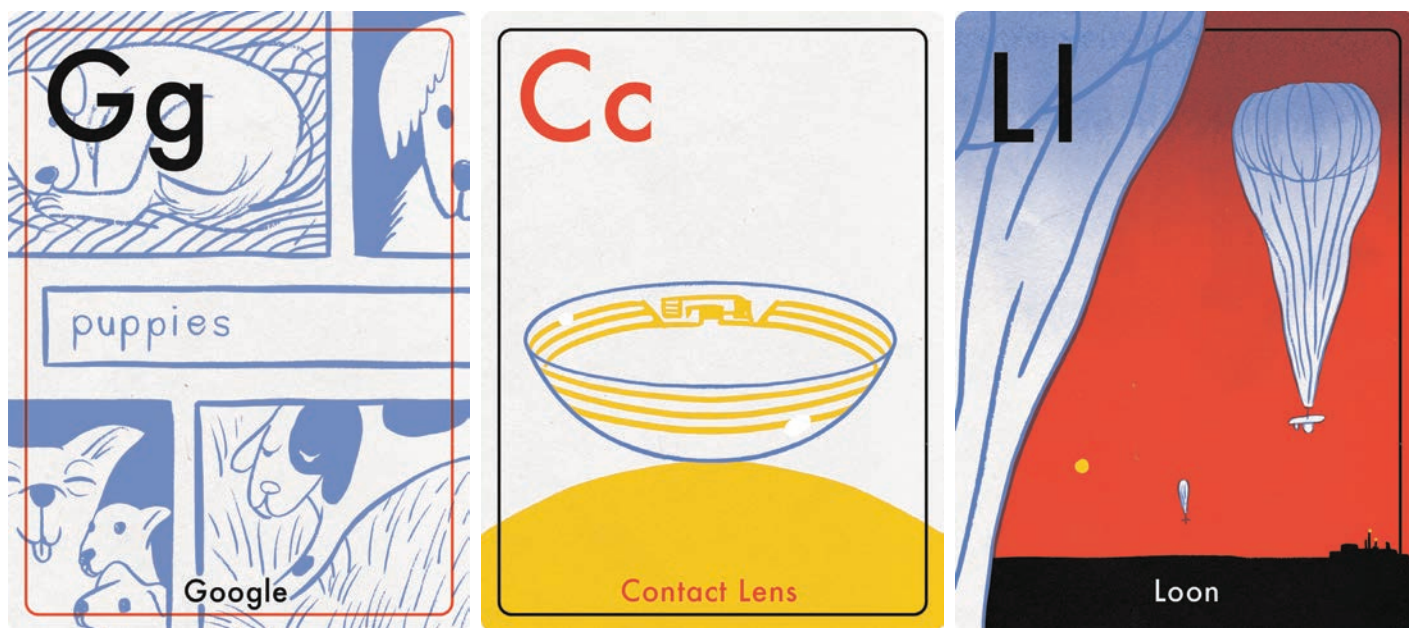### Learn More and Save Your Spot:
sxsw.com/tech2016

Follow Us: @sxsw

f t ⓘ ▶

What Will Alphabet Be When It Grows Up?

To truly change the world, Google's new holding company will need something that has eluded many previous industrial labs: an effective commercialization strategy.

By Jon Gertner

One of the more interesting documents of the information age was posted on the Internet 11 years ago, as part of the initial public offering of Google. That document, signed by founders Larry Page and Sergey Brin, conveyed both a deep enthusiasm for technological innovation and a mistrust of Wall Street. Page and Brin suggested that it would be possible to balance risk-taking with a sense of fiduciary responsibility. They would implement "a corporate structure that is designed to protect Google's ability to innovate." Above all, Google would not be a company that existed merely to reap profits and expand market share—rather, it would aspire "to develop services that significantly improve the lives of as many people as possible." Page warned: "As an investor, you are placing a potentially risky long term bet on the team, especially Sergey and me."

By almost any measure—profits, growth, branding, products, employees—things have turned out well, though it's debatable whether AdWords, the product behind much of Google's immense wealth, has improved lives all that much. But, in any case, Google is no more. Or at least, the name Google lives, but as a part of the holding company known as Alphabet, which was announced by Page after the U.S. financial markets closed on August 10. In the reorganization, the profitable parts of the Google empire—its business in Web search and advertising, along with YouTube and Google Maps—will stay in an area of the company that stock analysts tagged as "core Google." The rest of Page and Brin's now-sprawling conglomerate, including its R&D lab known as Google X, its inchoate forays into life sciences and life extension, and Nest Labs, its household products division—in other words, all the parts of the vast empire that don't make money—will be given a large degree of autonomy.

HANNAH K. LEE

Nest

Wing

Self-driving Car
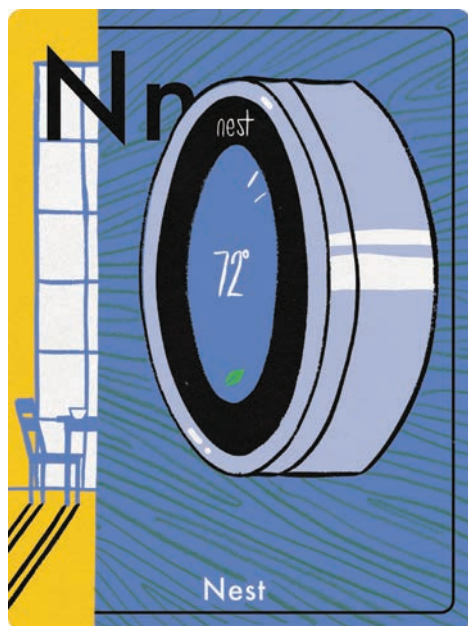
You could interpret the reorganization in purely financial terms—as a practical move meant to give Wall Street greater clarity about the profits of core Google and the investments being sunk into more speculative ventures such as X, which has developed a self-driving car and high-altitude balloons that deliver Internet access. Page acknowledged the validity of this view in his announcement of Alphabet, noting that the shake-up would make his company "cleaner and more accountable." Beyond the financial outlook, though, a more interesting question arises: will Alphabet be able to demonstrate a productive new path for industrial innovation?

The story of Bell Labs, founded in 1925 as the R&D lab of AT&T during the era (1913–1984) in which AT&T enjoyed a monopoly on U.S. telephone service, can help answer that question—and point to the challenges Alphabet will

Google's 2004 Founders' IPO Letter

Announcement of Alphabet, August 10, 2015

face. Bell Labs created many of the foundational technologies of the information age, including the transistor, many early lasers, communication satellites, and the UNIX operating system. It represents our best example of what an innovative, technology-focused industrial organization can accomplish. It was not only the country's most elite industrial lab; it was, for many decades, among the world's most elite institutions for research in mathematics, physics, and materials science. It was also where the formalized study of acoustics, semiconductors, and cellular communications first flourished.

There are a fair number of Bell Labs admirers and former staffers working within Google. And almost certainly, Google's willingness to push boundaries and fund projects for an unusually long time gives us the closest analogue to a Bell Labs of the modern era. After all, Google too is more or less a monopoly, and it is

funding its research largesse out of the rather mundane business of AdWords, just as AT&T funded some of the world's most impressive physics research by selling telephone service.

Still, it's important to keep in mind that while much of Bell Labs' reputation rests upon the breakthroughs of its research department, its less glamorous but far larger development department did much of the organization's heroic work. John Pierce, one of Bell Labs' research managers, once said the organization's structure reflected the fact that "pursuing an idea takes, I presume, 14 times as much effort as having it." It was a keen insight born of Pierce's decades of experience. Creating a functional product from breakthrough science—the transistor, for instance—required not only extraordinary effort but also an extraordinary amount of time.

Another distinction is crucial. Bell Labs organized its R&D efforts around communications-related pursuits—the

only way to justify work funded by its parent company, AT&T. This was a broad enough directive to allow all sorts of peripheral work in physical chemistry and even astronomy. There was room for flexibility, especially in the math department: before he came to MIT, Claude Shannon, whose theories on information paved the way for efficient digital communications, sometimes spent entire days tinkering with computerized chess programs and automated gadgets. Yet the policy was strict enough to lead to the departure of one of the most brilliant physicists of the 20th century, John Bardeen, a coinventor of the transistor, who fled Bell Labs partly because of frustration after his work on superconductivity was deemed tangential to communications research. It's doubtful something like this would happen at Google (or at Alphabet). In fact, over the years, Google has consistently and intentionally funded expensive R&D work that is unrelated to its core business, which may be the single most astonishing aspect of Page and Brin's management regime.

Over the past few decades, Wall Street's ability to reward shorter-term, risk-averse thinking has hobbled the once formidable research labs of corporations like IBM and has driven virtually every major American tech company away from basic and more ambitious applied research. Google has so far found a model that allows it greater flexibility than its rivals. There are two reasons for this. The first is the insane profitability of Google's advertising business. The second is Page and Brin's extraordinary—some might also say naïve—desire to spend money on risky new ideas.

Their ownership stakes give them that right. But in looking ahead to Alphabet's prospects, it's worth defining more precisely what success would mean. It seems reasonable to think that more mature parts of Alphabet—such as YouTube and Nest, both of which happen to be acqui-

sitions—could eventually become engines of growth that would complement the huge profits flowing from Google's core advertising business. It likewise seems plausible that some of Google's investments in young, information-oriented companies can blossom into something highly profitable, too. Meanwhile, it's useful to remember that Page and Brin are sometimes content to take a portfolio approach to R&D; if one of their new ideas has scant profits but a large impact (as measured by its number of users, for instance, or its ability to attract talented engineers), they will let it be subsidized by more lucrative forays.

One of the lessons of 20th-century industrial research is that the engineering, business, and even sales sides of a company can bring insights.

But as for the grander ambition here, to rapidly create a string of innovations that will drastically change the way we live and work—the prospects for that kind of success seem dubious, at best. Alphabet's life-extension division Calico, for instance, while stocked with talent, is a self-described moon shot, as are most of the projects at Google X. Moreover, Calico, which is pursuing a deeper understanding of the aging process, does not seem to fit with the larger organization, except in how it can divert Google's profits and benefit from Page and Brin's Medici-like patronage.

History suggests that organizing complex, innovative efforts around particular technologies (communications in Bell Labs' case) is more than just an act of convenience. It increases the odds of success, because development expertise reinforces research, and manufacturing expertise feeds back into ongoing technological development. One of the lessons of 20th-century industrial research is that

the engineering, business, and even sales sides of a company can bring insight to the innovation process. It would be nice to be wrong here—to see Calico extend our lives by a few years. But I suspect we'll need to look beyond Alphabet for new and more focused models of industrial innovation.

The riskiest technologies being seeded by Google's founders could indeed blossom into something publicly transformative *in time*. That was the case at Bell Labs, whose research later helped give rise to innovations at Intel, Texas Instruments, and even Apple, Microsoft, and Google. The same can be said for PARC, the Xerox research lab that created Ethernet and the graphical user interface but was unable to commercialize them. But Bell Labs' biggest ideas, which at best took decades to commercialize, didn't ensure the company's long-term success in the competitive environment brought on by the breakup of its monopoly. That's a bitter truth about making big bets on world-changing technologies: often, commercializing the innovative idea is far more important, and more difficult, than coming up with it in the first place. John Pierce knew what he was talking about.

If Alphabet is going to succeed in fulfilling Page and Brin's grand ambitions, it will need to figure out the piece of the innovation puzzle that ultimately eluded Bell Labs and PARC. How do you commercialize advances unrelated to your core strengths? Who exactly is going to manufacture and sell all those driverless cars? How do you make a business out of antiaging research? Solving that part of the innovation cycle would be a true breakthrough.

Jon Gertner is the author of The Idea Factory: Bell Labs and the Great Age of American Innovation.

MIT | PROFESSIONAL EDUCATION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

EXPAND YOUR KNOWLEDGE WITH MIT PROFESSIONAL EDUCATION PROGRAMS

Looking for a way to boost your knowledge and advance your career? MIT Professional Education gives technical professionals an added edge by providing crucial and timely knowledge in specialized science and engineering fields through an array of program offerings. Taught by world-renowned faculty from across the Institute, these programs provide a gateway to MIT expertise and give participants the opportunity to further their careers, elevate organizational performance and help make a difference in the world.

MIT Professional Education includes intensive one to five day programs, self-paced digital programs, full-semester on-campus MIT courses, custom programs at your company location and even short courses at international locations.

▶ SHORT PROGRAMS

Short Programs offer more than 50 intensive programs addressing new and evolving technologies, challenges and breakthrough solutions. Courses combine learning from MIT's groundbreaking research with real-world application perspectives from industry, government and academia.

▶ DIGITAL PROGRAMS

Digital Programs allow busy professionals globally to take courses taught by MIT faculty, from any location and at their own convenience. These online programs focus on important industry topics relevant to a variety of professionals around the world.

Upcoming offerings include:	Tackling the Challenges of Big Data	Cybersecurity: Technology, Application and Policy
	Oct 6 - Nov 17, 2015	Nov 10 - Dec 22, 2015
	Nov 17 - Dec 29, 2015	Jan 12 - Feb 23, 2016

▶ ADVANCED STUDY PROGRAM

Designed for professionals who wish to obtain in-depth knowledge in topics of their choice, this program offers qualified students the ability to attend regular, full semester MIT courses as ASP Fellows, without having to enroll in a degree program. Fellows earn academic grades and credits in addition to a certificate from MIT Professional Education.

▶ INTERNATIONAL PROGRAMS

International Programs bring MIT research insights to real-world challenges, while allowing program attendees to develop productive new networks. Typically 2-5 days long, these market relevant courses address professional and corporate education held at international locations.

Learn more about MIT Professional Education and programs.

Visit **professionaleducation.mit.edu/techreview** or email **professionaleducation@mit.edu**

Demo

Dan Widmaier

David Breslauer

Spinning Synthetic Spider Silk

A California company may have figured out how to use genetic engineering to make extremely versatile fibers the way spiders can.

By Katherine Bourzac
Photographs by RC Rivera

Materials scientists have spent decades trying to mimic spider silk. Not only are some of these silks stronger than steel, but they have combinations of properties not found in synthetic fibers like the Kevlar used for bulletproof vests or the petroleum-based polyester found in clothes.

But while several companies have produced artificial silk for small-scale applications, it can't be widely used to create new kinds of tough, durable, lightweight, petroleum-free materials unless it can be made in very large volumes. A startup called
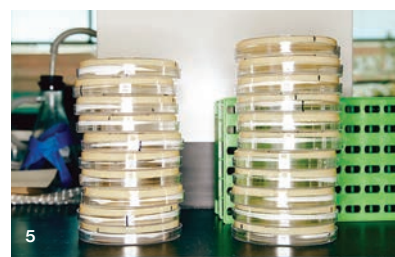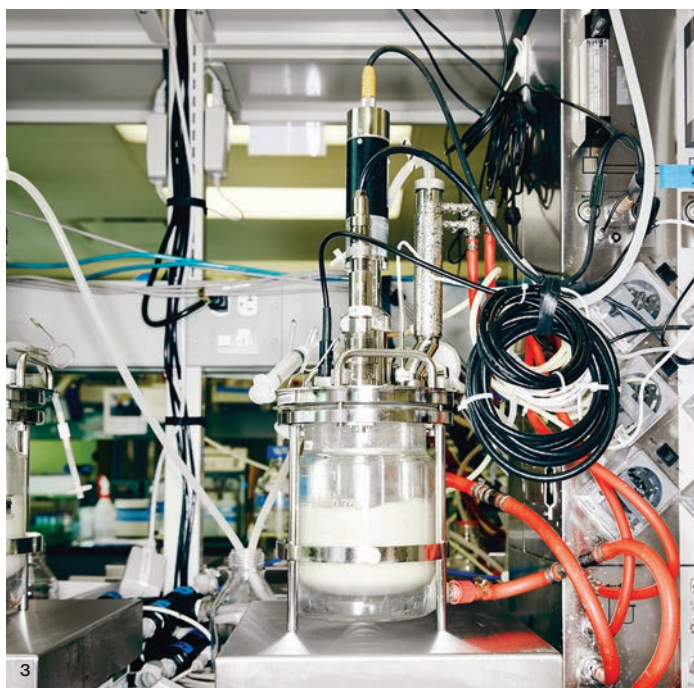
1 Inside this fermenting tank, genetically engineered yeast produce spider-silk proteins.

2 The yeast feed on sugary feedstocks such as this dextrose.

3 In a research-scale fermenter within a glass beaker, different growing conditions or proteins are tested.

4–5 Bolt's ultimate goal is to make fibers to customers' specifications. The first step is designing a new silk protein and engineering yeast that can produce it, like these experimental yeast inside an incubator and on petri dishes.

6 Purified spider-silk proteins are ready to be made into fibers.
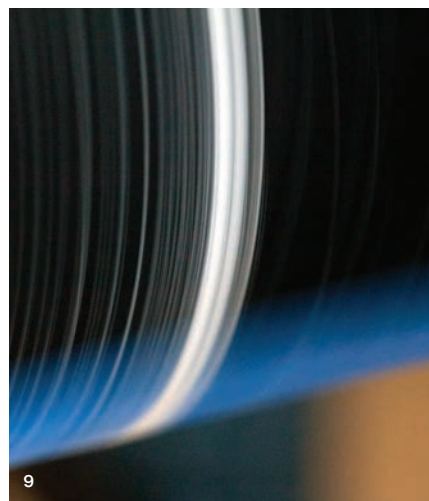
Bolt Threads, in Emeryville, California, might have found a way.

Two of its founders are Dan Widmaier and David Breslauer, who have been working on the problem since they were grad students at the University of California, San Francisco, and UC Berkeley in 2007. They use synthetic-biology techniques to engineer proteins that can be spun into fibers with properties they can alter depending on their customers' needs.

That versatility is crucial. While synthetic fibers made from petroleum tend to be good at one thing, silk can be reëngineered to suit diverse applications. Spiders themselves do this, fine-tuning their silk to make strong structural struts for their webs, sticky spots to capture prey, and a tough line to hang from.

At Bolt Threads, genetically engineered yeast brew silk proteins that can be spun into fibers. The properties of those fibers can be altered by tinkering with the protein concentration and the temperature, tension, and other aspects of the spinning process.

The company says its first products will be in consumer apparel in 2016. Its fibers, which are much finer than natural materials like cotton and stronger than nylon, could lend clothes the best qualities of both natural and artificial fibers: they would be soft and light, while durable enough to toss in the wash repeatedly. However, the company won't specify which properties it aims to achieve in its early products.

Widmaier and Breslauer do say, however, that clothes are only the beginning—an application that proves the company can manufacture at large volumes. "If we can get it to that scale," Widmaier says, "we can do anything." ✚
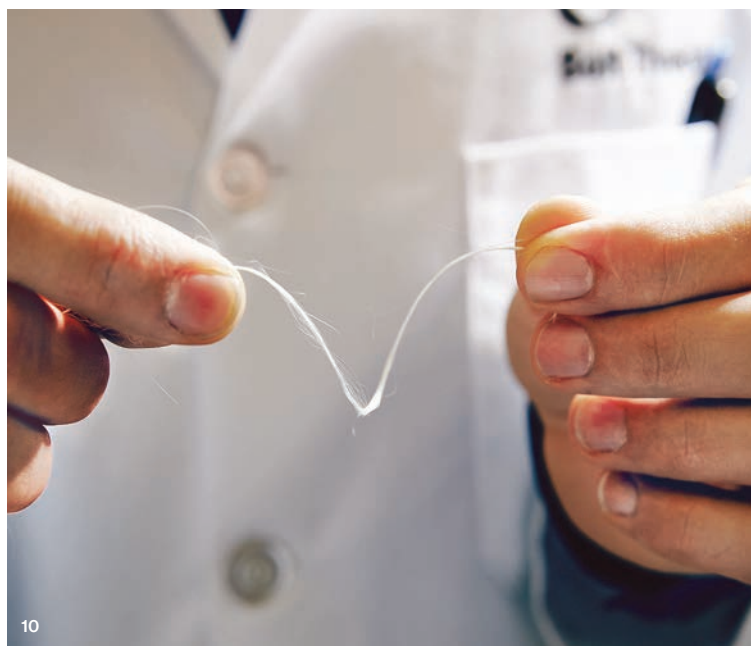

7 Part of the fiber-making apparatus. During the spinning process, fibers are extruded from a solution of protein, run through baths, and dried.

8 This machine is used to test the mechanical strength of experimental fibers.

**9** After being spun and treated, the silk fibers are spooled.

10 Breslauer holds threads of artificial spider silk, ready to be woven into textiles.

THE GREAT COURSES

Improve Your Memory and Communication Skills with These Lessons You Can Take in Your Home or Car
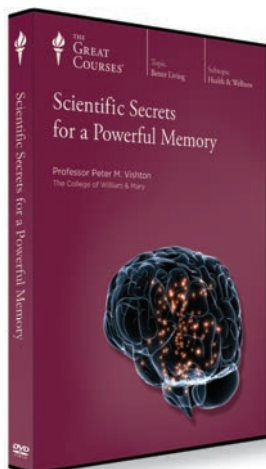
Memory is the most powerful tool of everyday life. Memory gives you the power to plan, to reason, to perceive, and to understand. In **Scientific Secrets for a Powerful Memory**, you'll explore the real research on how memory functions—and then apply these findings to help you make better use of the memory abilities you have. You'll emerge with the ability to process information more effectively and to increase your chance of remembering almost anything.

Course No. 1965
6 Lectures
(30 Minutes/Lecture)
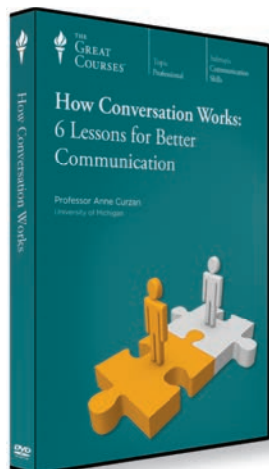
One of the most important things you do on a daily basis is converse with others. Fortunately, it's a skill set anyone can acquire and refine. **How Conversation Works: 6 Lessons for Better Communication** will teach you key strategies that can dramatically improve your ability to speak with anyone, from strangers to supervisors. Focus on the fundamental principles you need to become more conversationally aware and savvy at home, at work, and beyond.

Course No. 9382
6 Lectures
(30 Minutes/Lecture)
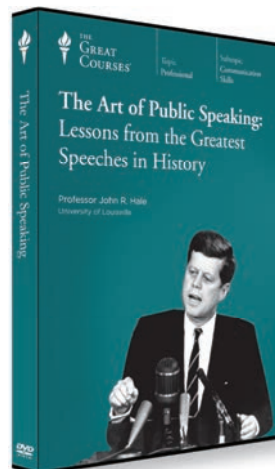
Improve and enhance your public-speaking skills with time-tested techniques and strategies used by great orators in **The Art of Public Speaking: Lessons from the Greatest Speeches in History**. These 12 engaging and accessible lectures offer you helpful insights into preparing for public speaking, crafting a great speech, and handling your audience. Learn the secrets of what makes history's enduring speeches unforgettable, and speak better on any subject.

Course No. 2031
12 Lectures
(30 Minutes/Lecture)
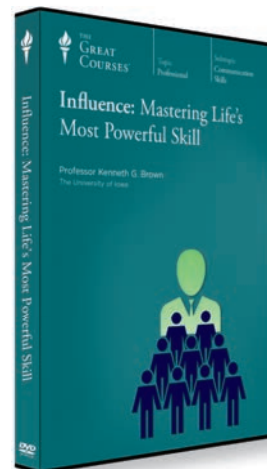
Whether you realize it or not, you're constantly surrounded by people and groups trying to influence you. You can actively take charge of your decisions by grasping the science behind how influence works. In **Influence: Mastering Life's Most Powerful Skill**, discover everything you need to tap into the hidden powers of influence and persuasion—and use them to enhance your personal and professional life in ways you never thought possible.

Course No. 5972
12 Lectures
(30 Minutes/Lecture)

SPECIAL INTRODUCTORY OFFER!

Over 14,000,000 courses sold since 1990!
THE GREAT COURSES

Order any one of these
BEST-SELLING COURSES for only:

$9.95 on CD or DVD

+$5 Shipping and Handling
Priority Code: 119601

All orders subject to approval.
Limit of one order per household.
Cannot be combined with any other special offers or promotions.
Offer valid for new customers only.

LIMITED TIME OFFER
SAVE up to $190
ORDER BY JANUARY 2

ORDER TODAY! Sale Ends Saturday, January 2, 2015!

www.THEGREATCOURSES.com/9TECH   **1-800-832-2412**

39 Years Ago

The Case for the Cab

Decades before Lyft and Uber, a scholar of transportation argued that the most efficient public transport system might be an army of less-regulated taxis.

"The urban traveler wants good door-to-door service which is free from waiting, walking, transferring, and crowding and which provides comfort, privacy, and convenience. And the urban traveler has made it clear that he will use a private automobile when he can afford it because it comes closer to providing what he wants than any other available mode of travel.

Private automobiles and taxicabs, quite simply, can provide attractive and convenient door-to-door service at a price that most travelers are willing and able to pay. The preference for the automobile and against transit is anything but a man-auto love affair; it is a choice for good but expensive service in contrast to poor but cheap service.

Given some reasoned tinkering with regulation, pricing, and operation, taxicabs might very well have a profound and lasting impact on transit patronage and lead to reduced automobile commuting. This question of regulation is important because the few studies conducted so far show that riders are more sensitive to the availability of taxis than they are to speeds or travel times. Restrictions also inevitably increase fare levels over those that would prevail without the artificially created 'virtual monopoly.' A taxicab license or medallion in New York, Boston, or Chicago, for example, has in recent years cost a new owner in the range of $6,000 to $35,000. This cost is passed on to the passenger; it reduces the numbers of people who can afford to take cabs, and that increases the fare for those who do and invariably lowers the available supply of taxicabs.

Except for a handful of cities, travelers are limited to just two transit options—bus and private automobile. A third choice—pervasive taxi service—could be easily added, and the most compelling argument for doing so can be made by asking what new transportation systems will best meet the needs of people who most need help.

With bus and rail patronage steadily declining, with affluence and the desire for decent service increasing, and with concern for the poor, handicapped and autoless growing, unleashing the taxicab is clearly the next move to improve public transportation in our cities."

Excerpted from "Increasing the Taxi's Role in Urban America," by Martin Wohl, a professor of transportation system planning at Carnegie Mellon University, from the July/August 1976 issue of Technology Review.

We create chemistry that makes more power love a cleaner drive.

The price of increased mobility is higher emissions. While people won't be slowing down any time soon, chemistry is getting us from A to B with a cleaner footprint.

One way we are improving the ecological impact of cars is with fuel additives that reduce emissions while increasing fuel efficiency. We also develop materials that give electric car batteries a higher energy capacity, to ensure that e-mobility is becoming a more attractive way to travel.

When better performance also means lower impact, it's because at BASF, we create chemistry.

To share our vision visit wecreatechemistry.com/automotive

150 years

■□■ **BASF**

We create chemistry

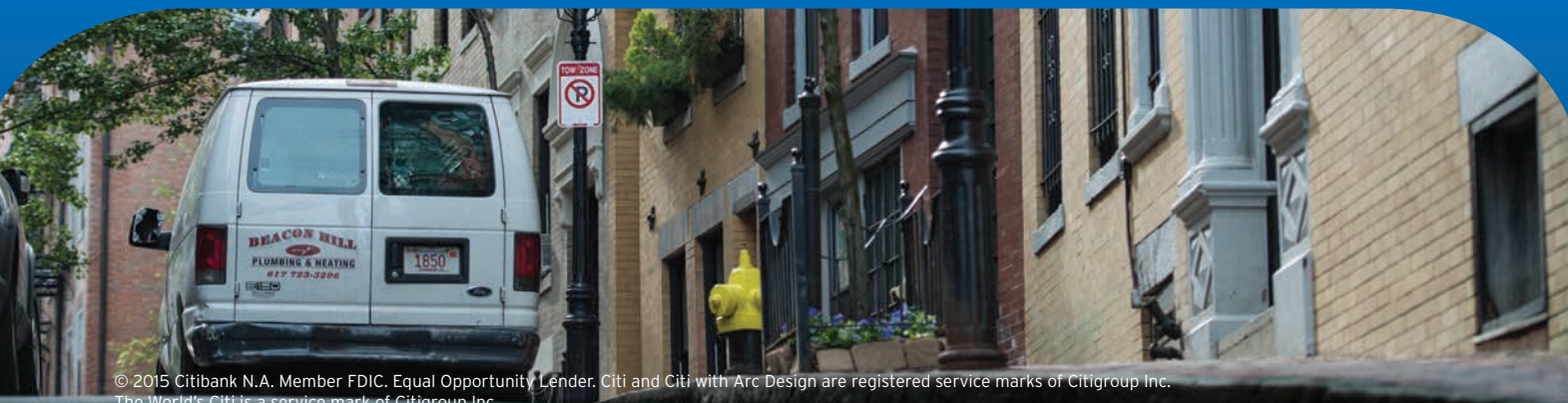# THEY MAY BE CALLED SMALL BUSINESSES, BUT THEIR IMPACT IS HUGE.

In the United States, over 50% of the working population is employed by small businesses. How can we make sure these companies grow and thrive?

Fleetmatics' mobile workforce solutions are making small vehicle-dependent businesses more competitive and efficient. But to help entrepreneurs everywhere, Fleetmatics needed a global bank. Working with Citi was critical to their growth. Now, they are not only helping improve productivity and create jobs in the U.S., but throughout the world.

For over 200 years, Citi's job has been to believe in people and help make their ideas a reality.

citi.com/progress

citi®
The World's Citi ℠